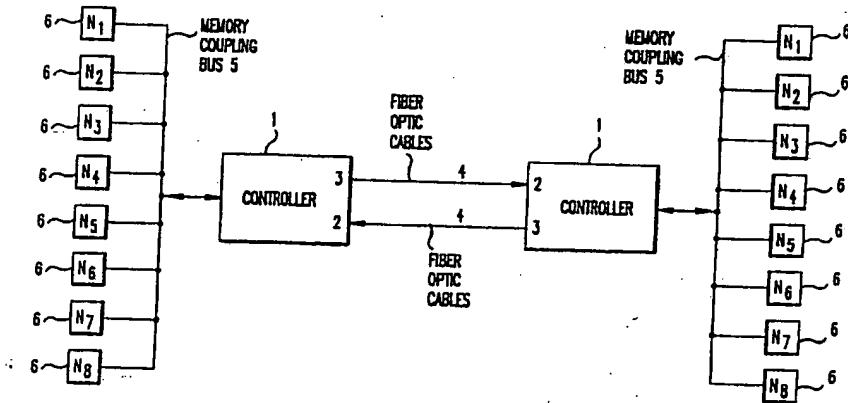




## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(54) Title: FIBER OPTIC MEMORY COUPLING SYSTEM



## (57) Abstract

A system for coupling sets of plurality of nodes (6) that are memory coupled to pass write only data memory to memory via a data link (4) that further includes an optical fiber controller (1) coupled to each data link (4). Each controller (1) is interconnected through fiber (4) for high speed data transfers from one set of nodes (6) to another. The controller (1) is capable of connection implementing three and four cable interfaces. The data is transmitted through the fiber (4) serially but the controller (1) is adapted to receive parallel data and convert to serial form and vice versa.

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## FIBER OPTIC MEMORY COUPLING SYSTEM

FIELD OF THE INVENTION

This invention relates to a novel fiber optic memory interconnection for linking special memory busses of processing nodes and has particular application for real time data processing systems operating at large distances.

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BACKGROUND OF THE INVENTION

Systems for updating memories in coupled nodes are known from U.S. Patent No. 4,991,079 the content of which is here incorporated by reference and from U.S. Serial No. 07/403,779 filed September 8, 1989, which is a continuation of Serial No. 06/880,222 filed June 30, 1986, now abandoned, the content of which is here incorporated by reference, all of which are commonly owned with the present application. Such systems use two ported memories and are used to transfer writes to one memory in one node automatically and at high speed to memory in other nodes with the intervention of a CPU. Such systems, however, have a distance limitation of about 120 feet and eight nodes. The present invention is an improvement that enables such systems to be connected over a distance. The present state of the art allows for connections of 3 kilometers and up to ten kilometers with a high speed data interface.

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SUMMARY OF THE INVENTION

The present invention provides a means for connecting such memory coupled processing systems over a large distance and provides for high speed data transfers between the systems, copying data from the memory of a node in one system to the memory of a node in another system.

Other and further advantages of the present invention will become readily evident from the following description of a preferred embodiment when taken in conjunction with the appended drawings.

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BRIEF DESCRIPTION OF THE DRAWINGS

3           Figure 1 illustrates the system of the present invention;

4           Figure 2 illustrates the fiber to memory coupled  
5 system controller (FMC);

6           Figure 3 illustrates the FMC to memory coupling bus interface;

7           Figure 4 illustrates the method of handling a memory write  
8 transfer by the FMC;

9           Figure 5 illustrates an example of address translation as  
10 performed by the present invention;

11          Figure 6 illustrates the FMC separated into data path  
12 quadrants;

13          Figure 7 illustrates Quadrant 0 of the FMC;

14          Figure 8 illustrates Quadrant 1 of the FMC;

15          Figure 9 illustrates Quadrant 2 of the FMC;

16          Figure 10 illustrates Quadrant 3 of the FMC;

17          Figure 11 illustrates a parallel/serial latch used in the  
18 present invention;

19          Figure 12 illustrates the basic packet format;

20          Figure 13 illustrates the format for a data packet;

21          Figure 14 illustrates the format for a general purpose async  
22 data packet;

23          Figure 15 illustrates the format for a data packet of a MCS-II  
24 multidrop console;

25          Figure 16 illustrates the format for an interrupt packet;

26          Figure 17 illustrates the mode of operation of the FMC for the  
27 handling of async serial data;

28          Figure 18 illustrates the mode of operation for handling  
29 special async data pass through;

30          Figure 19 illustrates handling of interrupts by the FMC;

31          Figure 20 illustrates an example of network linking clusters  
32 of nodes;

33          Figure 21 illustrates a secondary backup high speed link for  
34 the system;

35          Figure 22 illustrates internal loopback for memory write  
36 transfers;

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2       Figure 23 illustrates external loopback for memory write  
3 transfers;

4       Figure 24 illustrates memory coupling bus loopback;

5       Figure 25a illustrates internal loopback for general purpose  
6 async data;

7       Figure 25b illustrates external loopback for general purpose  
8 async data;

9       Figure 25c illustrates port-port loopback;

10      Figure 26 illustrates cluster FMC error handling;

11      Figure 27 illustrates hub FMC error handling;

12      Figure 28 illustrates typical configurations of the present  
13 invention;

14      Figure 29 illustrates a star configuration of the present  
15 invention.

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17 **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT**

18     This invention relates to a high speed data interface system  
19 using fiber optic memory interconnection as shown in Figure 1.  
20 This interface system connects memory coupled systems over  
21 distances up to 10 kilometers. Each memory coupled system  
22 comprises a data link or memory coupling bus 5 to which up to eight  
23 nodes 6 are coupled each comprising a processor, I/O, a two or more  
24 ported memory and a processor to memory bus. Write/read sense  
25 controllers couple the busses and the memory so writes only are  
26 sensed and reflected to the memories of other nodes without CPU  
27 intervention. This is described in detail in the patent and  
28 application noted above, both of which are here incorporated by  
29 reference. The bus 5 of each memory coupled system is connected to  
30 a fiber-to-memory coupling system controller (FMC) 1. Each FMC has  
31 both an input and output port for connection with another FMC. The  
32 input port 2 is for receiving transmitted data from another memory  
33 coupled system and the output port 3 is for transmitting data to  
34 another memory coupled system. The transmission of the data is  
35 through fiber optic cables 4.

36     The Fiber Optic Memory Coupling System (FOMCS) also provides

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2 the capability for nodes on separate MC busses to exchange async  
3 serial data across the fiber link and for a node on one MC bus to  
4 interrupt a node on another. Each FMC supports 8 general purpose  
5 async ports and 16 interrupt lines (8 input and 8 output). The  
6 multidrop console link incorporated in the MCS-II fourth cable is  
7 also supported. These features are intended to allow remote  
8 booting of nodes across the fiber and to provide a means of  
9 synchronizing the actions of nodes.

10 Throughout this document, the term "MCS cluster" (or simply  
11 "cluster") is used to refer to a MC bus and its attached nodes and  
12 FMCs. In configurations of only two or three clusters, pairs of  
13 FMCs are used to directly connect MC busses (see Figure 28). In a  
14 configuration of more than three clusters, a FOMCS hub is used to  
15 connect all the clusters in a star configuration (see Figure 29).

16 The configuration programming link shown in Figures 28 and 29  
17 is used to establish the operational mode of each FMC. FMCs which  
18 are not directly connected to the programming link receive  
19 programming information via packets sent over the fiber link. The  
20 FMC 1 can be seen in more detail in Figure 2. The FMC includes a  
21 Receive Data Path 7, an output latch 9, a receive FIFO 11, a  
22 receive Error Detection Circuit 13, two receive latches 15 and 17,  
23 a receiver 19, an input latch 10, a hit and translation RAM 12, a  
24 transmit FIFO 14, a transmit Error Detection Circuit 16, two  
25 transmit latches 18 and 20 and a transmitter 22.

26 The FMC 1 consists of four main sections: the memory coupled  
27 system 5 interface, the data paths (Rx and Tx) 7 and 8, the high  
28 speed serial data link interface 4, and the microprocessor. These  
29 areas are delineated using dashed lines in the functional block  
30 diagram (Figure 2). The Fiber Transition Module (FTM) connects to  
31 the FMC high speed serial link interface. The FTM is a known and  
32 conventional piece of hardware and serves to connect the electrical  
33 signals to corresponding light signals and vice versa.

34 The Memory Coupling (MC) bus interface is the FMC's link to  
35 the Memory Coupling System (MCS) and the nodes on that bus. The  
36 FMC implements a three-cable, 90-signal interface for those MCS

1  
2 networks that use a standard MC bus (24-bit addresses), and a  
3 four-cable, 120-signal interface for those MCS networks that use  
4 the 28-bit addresses provided in MCS-II. Provision is also made in  
5 the four-cable interface for eventual support of 32-bit addresses.  
6 The FMC supports all the address lines defined in the four-cable  
7 interface; however, in an environment where addresses are a full 32  
8 bits, the FMC will only reflect into and out of the first 256  
9 megabytes of memory.

10 The FMC appears as a typical MCS node on the bus, using one  
11 of the nine bus IDs (0 - 8) available in MCS or MCS-II. The MCS  
12 used by the FMC is set during initialization by the configuration  
13 programming link.

14 Details of the FMC interface to the MC bus are illustrated in  
15 Figure 3. The FMC MC bus interface receives bus transfers by  
16 latching the memory address, memory data, flag bits and parity on  
17 the rising edge of DATA VALID (assuming DATA VALID is not being  
18 driven by the FMC itself). The two different bit counts for the  
19 address, flags and parity lines reflect differences between the  
20 three cable MCS bus and the four cable MCS-II bus. The smaller  
21 counts apply to the three cable bus. Note that 32 bits of address  
22 are indicated for the four cable MCS-II bus rather than 28. As  
23 mentioned earlier, signals to support the additional four address  
24 bits are reserved in the fourth cable for future expansion. One  
25 bit of odd parity is provided for each byte of address and data,  
26 resulting in the seven or eight parity bits shown in Figure 3.

27 The flag bits qualify the received transfer. For memory  
28 write transfers, one flag bit (referred to as the "F-bit")  
29 indicates whether the memory write is to a byte location in memory  
30 as opposed to a halfword or word. The other two flag bits, which  
31 are only present in the MCS-II bus, differentiate between memory  
32 write transfers and other types of transfers. While only memory  
33 write transfers appear on an MCS-II bus in a cluster, the MCS-II  
34 bus in the FOMCS hub is used to distribute interrupt, async and  
35 other types of data in addition to memory write traffic.

36 As indicated in Figure 3, the address, flags and parity are

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2 treated as 32, 3 and 8 bit quantities, respectively, when received  
3 by the FMC. If a three cable MCS bus is connected to the FMC, the  
4 receivers for the eight most significant address bits, the two  
5 extra flag bits and the eighth parity bit are disabled. Zeros are  
6 put in the MC input latch for the missing address and flag bits and  
7 a one is inserted for the missing parity bit. In a four cable  
8 environment, 32 bit addresses are received but the FMC will discard  
9 any received memory write transfer in which the most significant  
10 four address bits are not zero.

11 If receipt of a transfer causes the FMC Tx FIFO 14 to become  
12 half full, the FMC will drive GLOBAL BUSY on the MC bus to prevent  
13 overflow. GLOBAL BUSY is deasserted when the Tx FIFO 14 becomes  
14 less than half full. The CONTROL BUSY signal is only present in  
15 the MCS-II bus and is only utilized in the FOMCS hub. If receipt  
16 of a non-memory-write type transfer causes the FMC FIFO used to  
17 hold such transfers to become half full, the FMC will drive CONTROL  
18 BUSY to prevent overflow. When the FIFO becomes less than half  
19 full, CONTROL BUSY is deasserted.

20 Before the FMC can generate a transfer on the MC bus, it must  
21 first acquire the right to access the bus. To accomplish this, the  
22 FMC asserts the REQUEST line on the bus which corresponds to the  
23 MCS ID the FMC has been programmed to use. The FMC then monitors  
24 the corresponding GRANT line. When the bus arbiter asserts the  
25 GRANT line, the FMC drives the memory address, memory data, flag  
26 bits and parity on the bus. The FMC's MCS ID is also driven on the  
27 node id lines of the bus. On the next rising edge of the VALID  
28 ENABLE signal, the FMC drives DATA VALID. (The VALID ENABLE signal  
29 is a free running clock generated by the bus arbiter to synchronize  
30 the actions of nodes on the bus.)

31 Note that the MC output latch illustrated in Figure 3 only  
32 supplies 28 bits of the memory address rather than 32. The driver  
33 inputs for the remaining four address bits are tied to ground  
34 (i.e., the bits are forced to be zeros).

35 If receipt of a memory write transfer packet causes the FMC  
36 Rx FIFO 11 to become half full and MC bus burst request mode is

1  
2       enabled, the FMC will drive BURST REQUEST. Asserting the BURST  
3       REQUEST signal, which is only present in the MCS-II bus, causes the  
4       bus arbiter to enter a mode in which only the FMC is granted access  
5       to the bus. After asserting BURST REQUEST and delaying long  
6       enough to guarantee propagation of the signal to the arbiter, the  
7       FMC deasserts GLOBAL BUSY. If no other node on the bus is  
8       asserting GLOBAL BUSY, the arbiter will begin issuing grants to the  
9       FMC. If one or more other nodes is asserting GLOBAL BUSY, the  
10      arbiter waits for the busy condition to clear and then begins  
11      issuing grants to the FMC. Note that the FMC can safely deassert  
12      GLOBAL BUSY even if it is unable to accept more transfers from the  
13      bus because the arbiter will only grant bus access to the FMC.

14      When the FMC has unloaded enough packets front its Rx FIFO 11  
15      to cause the fill level to drop below half full, BURST REQUEST is  
16      deasserted and the arbiter returns to the normal "fairness"  
17      arbitration scheme. If the FMC is unable to accept more transfers  
18      from the bus, it will assert GLOBAL BUSY before deasserting BURST  
19      REQUEST.

20      If the FMC's Tx FIFO is less than half full, the FMC will  
21      keep BURST REQUEST asserted for 8 MC bus cycles and then release it  
22      for 16 cycles and then assert it for 8, release it for 16 and so on  
23      until the Rx FIFO fill level drops below half full. If both the  
24      Rx and Tx FIFOs are half or more full, the FMC will assert BURST  
25      REQUEST continuously until enough packets have been unloaded from  
26      the Rx FIFO to cause the fill level to drop below half full. Once  
27      BURST REQUEST is deasserted, the arbiter returns to the normal  
28      "fairness" arbitration scheme. If the FMC is unable to accept more  
29      transfers from the bus, it will assert GLOBAL BUSY before  
30      deasserting BURST REQUEST.

31      Support for burst request mode in the FMC is enabled or  
32      disabled via a configuration programming command. Only one FMC on  
33      a given MC bus can have burst request mode enabled but at least one  
34      FMC in every FMC-to-FMC link must have the mode enabled to ensure  
35      reliable operation. Note that enabling burst request mode in the  
36      FMC only means that the FMC is able to drive BURST REQUEST on the

1 bus. For burst request mode to be useful, the four cable MCS-II  
2 environment with Memory Coupling Controllers (MCC's) as the bus  
3 arbiter/terminators is required. MCC's provide bus termination and  
4 arbitration in a conventional manner as known from the previously  
5 noted patent and application and are sometimes referred to as  
6 reflective memory controllers.

7 The FMC Rx and Tx data paths 7 and 8 move data between the  
8 MCS interface and the high speed serial data link. They also  
9 interface to the microprocessor allowing asynchronous data,  
10 interrupt transfers and flow control information to move between  
11 clusters.

12 Figure 4 illustrates the manner in which the FMC processes  
13 MCS memory write transfers. As indicated, not all transfers are  
14 transmitted as packets over the high speed serial data link. Only  
15 those transfers which correspond to memory writes into selected  
16 regions of memory are transmitted over the high speed link.  
17 Transfers which do not fall within these selected regions are  
18 simply discarded.

19 In the other direction, packets containing memory write  
20 transfers are received over the high speed link and decoded by the  
21 FMC. Note that in the Rx path 7 there is no hit/translation RAM so  
22 all memory write packets received over the high speed link cause  
23 memory write transfers to be generated on the MC bus. When a  
24 packet has been received which represents a write into memory, the  
25 FMC requests the use of the MC bus and when the request is granted,  
26 generates a memory write transfer on the bus.

27 In the Tx path 8, the regions of memory to be reflected are  
28 defined during configuration programming of the FMC. During  
29 programming, the total memory address space is viewed as a sequence  
30 of 8K byte (2K word) blocks. Multiple regions as small as 8K bytes  
31 can be defined. Any number of regions, segregated or concatenated,  
32 up through the entire address range may be established.

33 Another feature of the FMC which is illustrated in Figure 4  
34 is memory address translation. Prior to packetizing a memory  
35 write transfer and transmitting it over the high speed link, the

8        Note that the least significant 13 bits of a memory address  
9        are unaffected by the translation process. Thus, 8k byte blocks  
10      are mapped from the address space of the source MC bus to that of  
11      the destination MC bus and vice versa. As illustrated in Figure 5,  
12      this feature is very useful because it allows clusters to share  
13      memory regions which reside in the different places in each  
14      cluster's physical address space.

15 The contents of the hit/translation RAM are established

16

1 during configuration programming of the FMC. The size of memory  
2 addresses (i.e., 24 or 28 bits) on the source MC bus is also  
3 established during configuration programming. Each location in the  
4 hit/translation RAM represents a 8K byte block of memory and  
5 contains a hit bit and the 15 bit translation value. If the hit  
6 bit is set, memory writes into the 8K byte memory block are  
7 reflected over the high speed link. If the bit is reset, such  
8 memory writes are ignored.

9 In the context of the MCS star network configuration, the FMC  
10 region selection and address translation features can be used to  
11 segregate the MCS clusters connected to the hub into groups such  
12 that memory write traffic is only reflected within a group, not  
13 between groups. Note that if an administrative system (i.e., not  
14 one of the nodes in the star network) is used to program the FMCs,  
15 a secure network can be achieved in which cluster groups can  
16 coexist but not affect each others memory. If total isolation of  
17 groups is not desired, overlapping regions can be used.

18 The FMC microprocessor has the ability to interject data into  
19 and remove data from both the Tx and Rx data paths 7 and 8. Such  
20 data is referred to as control data to distinguish it from memory  
21 write transfers. General purpose async data, MCS-II multidrop  
22 console async data and interrupt pulses are all treated as control  
23 data.

24 When the FMC receives data over the general purpose async  
25 ports, it forms the data into packets and injects those packets  
26 into the transmit data stream sent over the high speed link. When  
27 a packet of async data is received by the FMC, the bytes are broken  
28 out of the packet and sent over the appropriate general purpose  
29 async port. MCS-II multidrop console data is handled in a similar  
30 fashion.

31 When an enabled input interrupt line is pulsed, the FMC  
32 generates a packet that is sent over the high speed link. Upon  
33 receipt of an interrupt packet from the serial data link, the FMC  
34 pulses the appropriate output interrupt line.

35 Other control transfers include configuration programming

1 information, high availability messages, error indications, and  
2 reset indications.

3 Flow control in a MCS network is accomplished by means of  
4 flow control bits in the packets sent from FMC to FMC and by means  
5 of MC bus busy signals. Internal to the FMC, memory write data  
6 transfers and other types of data transfers (i.e., async,  
7 interrupt, multidrop, etc.) are handled separately so that flow  
8 control may be applied to non-memory write transfers without  
9 affecting the memory write traffic. Each packet sent from FMC to  
10 FMC contains two flow control bits, one to cause the receiving FMC  
11 to cease or resume transmission of memory write transfer packets  
12 and another to cause it to cease or resume transmission of other  
13 types of packets. This notion of two separate data streams also  
14 applies to the hub MC bus where there are separate bus busy  
15 signals, one for memory write transfers and another for all other  
16 types of transfers.

17 An additional type of flow control is burst request mode.  
18 Burst request mode is necessary to ensure that lock ups do not  
19 occur on FMC-to-FMC links. When link utilization is high in both  
20 directions, the potential exists for a FMC-to-FMC link to lock up  
21 in a condition in which both FMCs are asserting busy on their  
22 respective MC busses. Because the busy condition on the MC busses  
23 prevents the FMCs from generating bus transfers, the FMCs are  
24 unable to reduce the fill levels of their Tx FIFOs 14 and will  
25 therefore never deassert bus busy.

26 Burst request mode alleviates this problem by allowing a FMC  
27 to unload transfers from its Rx FIFO 11 while ensuring that the FMC  
28 will not have to accept additional transfers into its Tx FIFO 14.  
29 This means the FMC can accept more memory write transfer packets  
30 from the remote FMC which in turn allows the remote FMC to unload  
31 its Tx FIFO 14 and eventually clear the busy condition on the  
32 remote MCS bus. Clearing the busy condition allows the remote FMC  
33 to unload its Rx FIFO 11. The remote FMC can then accept more  
34 memory write transfer packets which allows the local FMC to unload  
35 its Tx FIFO 14 and clear the busy condition on the local MC bus.

1 As shown in Figure 6, the FMC data paths are logically  
2 subdivided into quadrants. In quadrant 0, MC bus transfers are  
3 received and moved to the Tx FIFO 14. The Tx FIFO 14 serves as the  
4 boundary between quadrants 0 and 2. In quadrant 2, transfers  
5 removed from the Tx FIFO 14 are packetized and transmitted over the  
6 high speed serial link 4.

7 Packets are received over the high speed link 4 in quadrant  
8 3 and the packet contents are moved to the Rx FIFO 11. The Rx  
9 FIFO 11 serves as the boundary between quadrants 3 and 1. In  
10 quadrant 1, information removed from the Rx FIFO 11 is used to  
11 generate transfers on the MC bus.

12 An important feature of the FMC design, particularly from a  
13 diagnostic perspective, is that the latches in each quadrant can  
14 be accessed in both a parallel and serial fashion. During normal  
15 operation of the FMC, data moves through the latches using the  
16 parallel interface. The alternate serial interface allows the  
17 microprocessor on the FMC to shift data serially into and out of  
18 the latches.

19 Figure 7 shows a detailed view of quadrant 0. Processing  
20 begins in quadrant 0 when the control logic 25 detects that the MC  
21 input latch 10 has been loaded. The input latch is unloaded and  
22 odd parity is computed on the address and data. The computed  
23 parity is then compared to the received parity. At the same time,  
24 the most significant address four bits are checked to see if any  
25 of them are non-zero.

26 While the parity and address checks are taking place, 15 bits  
27 of the address are used to address the hit/translation RAM 12. (If  
28 the address came from a three cable MCS bus, the upper four of the  
29 15 bits used to address the RAM will be zeros.) The least  
30 significant 15 bits of the 16 bit value read from the RAM become  
31 the new, or translated, address bits. The most significant bit  
32 of the value read from RAM is the window hit bit.

33 The destination of the MC transfer is determined by the  
34 parity and address checks, the hit bit, and the flag bits received  
35 with the transfer. If any of the most significant four address bits

1       is non-zero, the transfer is discarded. If the received parity  
2       does not equal the computed parity, the transfer is clocked into  
3       the microprocessor interface FIFO 21. The transfer is also placed  
4       into the micro FIFO if the parity is good but the flag bits  
5       indicate a control type transfer (which only occurs in the MCS  
6       hub). The destination of a memory write type transfer with good  
7       parity depends on the setting of the hit bit. If the hit bit is  
8       reset, the transfer is simply discarded. If the hit bit is set,  
9       the memory data, translated memory address and flag bits are  
10      clocked into the Tx FIFO 14.

11      The contents of the hit/translation RAM 12 are initialized  
12      by the FMC microprocessor. To change a location in the RAM 12, the  
13      microprocessor first puts the new value into the loading buffers  
14      24. The microprocessor then causes GLOBAL BUSY to be asserted on  
15      the MC bus and waits long enough for any transfer in progress to  
16      pass through the MC input latch 10. Then, the microprocessor  
17      causes the hit/translation RAM 12 to be written with the value from  
18      the loading buffers. GLOBAL BUSY is subsequently deasserted.

19      Figure 8 shows a detailed view of quadrant 1. Quadrant 1  
20      processing begins when the control logic 25 detects that the MC  
21      output latch 9 is empty and either the Rx FIFO 11 is not empty or  
22      the micro interface 21 is requesting use of the latch 9. If there  
23      is something in the FIFO 11 and the micro interface 21 is not  
24      requesting, the FIFO 11 is read and parity is computed on the  
25      memory address and data. The data, address, flags and computed  
26      parity are then clocked into the MC output latch.

27      The micro interface 21 is only used when a FMC in a FOMCS hub  
28      needs to distribute interrupt, sync or other control information  
29      to the other FMCs in the hub. If control busy is not asserted on  
30      the hub bus, the micro interface logic 21 requests use of the MC  
31      output latch 9. When the latch 9 is available, the control data  
32      is serially shifted into the latch 9. Odd parity for the transfer  
33      is computed by the microprocessor and shifted into the latch 9  
34      following the data.

35      Figure 9 shows a detailed view of quadrant 2. Processing

1 begins in quadrant 2 when the control logic detects that the Tx  
2 latches 18 and 20 are empty and finds that the Tx FIFO 14 is not  
3 empty or that the microprocessor has loaded the micro interface  
4 latch. If the micro latch has been loaded, the contents of the  
5 latch are transferred to the Tx latches 18 and 20. Of the 72 bits  
6 transferred from the micro latch, 64 are also clocked into a pair  
7 of EDC (error detection code) generators 16a and 16b. The  
8 generated eight bit EDC and the 72 bits from the micro latch are  
9 clocked into the Tx latches 18 and 20. The contents of the Tx  
10 latches 18 and 20 are then passed to the high speed link serial  
11 transmitter 22 in two 40 bit transfers.

12 If the micro latch is empty but the Tx FIFO 14 is not, the  
13 memory data, address and flags are read from the FIFO 14. An  
14 additional nine bits are generated by the control logic to make a  
15 total of 72. Again, an EDC is generated on 64 of the 72 and an 80  
16 bit packet is clocked into the Tx latches 18 and 20. The contents  
17 of the Tx latches 18 and 20 are then passed to the transmitter 22.

18 If the control logic detects that either the Rx FIFO 11 or the  
19 micro FIFO in quadrant 3 are half full, flow control flag bits are  
20 asserted in the 80 bit packet clocked into the Tx latches 18 and  
21 20. If no packet is available to clock into the latches, the  
22 control logic 25 causes a special flow control packet to be clocked  
23 into the Tx latches 18 and 20 for transmission to the remote FMC.  
24 Separate flow control bits are defined for the Rx FIFO 11 and the  
25 quadrant 3 micro FIFO so that the flow of memory write and non  
26 memory write packets can be throttled separately. Once the FIFO(s)  
27 become less than half full, a packet is sent to inform the remote  
28 FMC that it can resume transmission of one or both types of  
29 packets.

30 Figure 10 shows a detailed view of quadrant 3. Quadrant 3  
31 processing begins when the first 40 bits of a packet are received  
32 over the high speed serial link. Control logic 25 causes the 40  
33 bits to be clocked into a staging latch 15. When the rest of the  
34 packet arrives, the entire 80 bit packet is clocked into the Rx  
35 latch 17. From the Rx latch 17, 64 bits of the packet are moved

1 to a pair of EDC generators/checkers 13a and 13b. The received EDC  
2 is compared to that generated and an indication of the outcome is  
3 provided to the control logic.

4 The destination of the contents of the packet depend on the  
5 packet type bits examined by the control logic and the result of  
6 the EDC check. If the EDC check fails, the packet contents are  
7 moved to the micro interface FIFO 23. The packet contents are also  
8 moved to the micro FIFO 23 if the packet type flags indicate that  
9 the packet contains sync, interrupt or other control information.  
10 Otherwise, the memory address, data and flags are moved to the Rx  
11 FIFO 11.

12 Among the 12 packet bits examined by the control logic 25 are  
13 the flow control bits, one for throttling memory write packet  
14 transmission and the other for throttling non memory write packet  
15 transmission. A set flow control bit in a received packet causes  
16 the FMC to cease transmission of the corresponding type of packet  
17 until a packet is received with that flow control bit reset.

18 Figure 11 shows a block diagram of the AMD 29818 latch used  
19 to implement the MC input and output latches 9 and 10 and the Rx  
20 latches 15 and 17 and Tx latches 18 and 20 on the FMC. In the FMC  
21 design, the normal data path through these latches is the parallel  
22 one from the D input through the pipeline register 29 to the Q  
23 output. The alternate serial path is accessible by the FMC  
24 microprocessor and is primarily used for diagnostic purposes. Note  
25 that the mux 30 (which is controlled by the MODE signal) allows  
26 either the contents of the shadow register 31 or the D input to  
27 serve as the input for the pipeline register 29. Also, note that  
28 the output of the pipeline register 29 is feed back into the shadow  
29 register 31. Thus, with appropriate hardware control, data can  
30 enter the latch in serial and exit in parallel or enter parallel  
31 and exit in serial.

32 These features are exploited by the FMC design which allows  
33 the microprocessor to serially load a latch in one quadrant, move  
34 the data along the normal parallel path from that latch to a latch  
35 in another quadrant and then serially read the contents of the

1 destination latch. By comparing the data loaded into the first  
2 latch with that read back from the second, the microprocessor can  
3 determine if the data path is functional.

4 In the FOMCS architecture, the high speed serial link is  
5 implemented with a transmit/receive pair of Gazelle Hot Rod chips.  
6 The Gazelle Hot Rod transmitter chip converts 40-bit parallel data  
7 into serial data that is transmitted over a fiber or coax link.  
8 At the remote end of the link, the data is reconverted to the  
9 original parallel data by a Hot Rod receiver chip. Over this link,  
10 the FMCs exchange information in the form of 80-bit packets. The  
11 Gazelle transmitter sends each 80-bit packet as two 40-bit data  
12 frames. When no packet is available to send, the transmitter sends  
13 sync frames to maintain link synchronization.

14 The data on the serial data link is 4B/5B NRZI (Non-Return  
15 to Zero, Invert on ones) encoded. This allows the receiver to  
16 recover both data and clock signals from the data stream,  
17 precluding the need for a separate clock signal to be sent along  
18 with the data. Data rates as high as 1 Gbps (one billion bits per  
19 second) are supported.

20 Transmission error detection is accomplished via an eight  
21 bit error detection code (EDC) which is included in each packet.  
22 Of the 72 remaining bits in the packet, only 64 are included in the  
23 EDC calculation. The eight unprotected bits are the first four  
24 bits of each of the 40-bit halves of the packet.

25 The basic packet format is shown in Figure 12.

26 Bits 0 and 40 are used to distinguish the two 40-bit  
27 sections of the packet. When receiving a packet, a FMC always  
28 expects the first bit of the first 40-bit section to be a zero and  
29 the first bit of the second 40-bit section to be a one.

30 The BSD and BSC bits (bits 1 and 41, respectively) are used  
31 by the transmitting FMC to throttle transmissions by the FMC  
32 receiving the packet. The BSD bit is used to tell the receiving  
33 FMC to cease or resume transmission of memory write data packets;  
34 the BSC bit is used to tell the receiving FMC to cease or resume  
35 transmission of control packets. The bits are set to tell the

1 receiving FMC to cease the associated type of transmissions; they  
2 are reset to tell the receiving FMC to resume transmissions.

3 The TYP bit (bit 4) indicates the packet type. If the bit  
4 is reset, the packet contains a memory write transfer. If the bit  
5 is set, the packet is designated as a control packet. Control  
6 packets are used to transfer async data, interrupt data and any  
7 other type of information which FMCs must exchange.

8 The VAL bit (bit 5) indicates whether the cross-hatched  
9 portions of the packet (bits 6 - 39 and 44 - 71) actually contain  
10 any valid information. If the VAL bit is set, the receiving FMC  
11 will consider the information in the cross-hatched portions to be  
12 valid. If the VAL bit is reset, the receiving FMC will only pay  
13 attention to the flow control information encoded in the packet  
14 (i.e., the settings of the BSD and BSC bits). When a FMC does not  
15 have any data to send, it will periodically transmit packets with  
16 the VAL bit reset and the flow control bits set or reset as  
17 appropriate.

18 As mentioned earlier, bits 0 - 3 and bits 40 - 43 are not  
19 included in the EDC calculation. This means that the BSD bit  
20 and/or the BSC bit may be in error in a received packet and no EDC  
21 error will be detected. However, even if an invalid flow control  
22 indication is received and acted upon, the next packet received  
23 will almost certainly correct the problem.

24 The shaded portions of the packet (bits 2 - 3 and bits 42 -  
25 43) are reserved. The convention of shading reserved portions of  
26 packets is followed throughout this document.

27 Bits 72 - 79 contain the EDC which is computed on bits 4 - 39  
28 and bits 44 - 71. The EDC is an 8-bit check byte generated  
29 according to a modified Hamming Code which will allow detection  
30 of all single- and double-bit errors and some triple-bit errors.  
31 Because of the NRZI encoding scheme used by the Gazelle Hot Rod  
32 chips, noise on the high speed serial link medium will cause  
33 sequential double-bit errors which the receiving FMC will be able  
34 to detect by comparing the EDC in the packet to that computed  
35 during receipt of the packet.

1       The memory write transfer packet is used by the FMC to  
2 transmit a memory address and associated data over the high speed  
3 link. The address and data represent a memory write transfer which  
4 the FMC received from the MC bus. The format of the packet is  
5 shown in Figure 13.

6       The FBT bit (bit 7) is the F-bit associated with the memory  
7 write. The F-bit is set if the memory write transfer represents  
8 a write to a single byte of memory. The F-bit is reset if the  
9 transfer represents a write to a half-word or word.

10      Note that if the memory address is a 24-bit address, bits 44-  
11 47 of the packet will contain zeros.

12      The general purpose async data packet format is shown in  
13 Figure 14.

14      The packet can contain up to five bytes of async data. The  
15 first four bytes are placed in bits 8-39 with the first byte in  
16 bits 8-15, the second in 16-23 and so on. The fifth byte is placed  
17 in bits 64-71. The receiving FMC determines the actual number of  
18 data bytes in the packet by checking the Byte Count field (bits 45-  
19 47).

20      The Destination Cluster field (bits 48 - 55) contains the  
21 address of the MCS cluster for which the packet is ultimately  
22 intended. The FMC in the destination cluster uses the Destination  
23 Port field (bits 56 - 63) to determine which general purpose async  
24 port to use when transmitting the async data decoded from the  
25 packet.

26      The BRK bit (bit 44) indicates that the originating FMC  
27 received an async break indication. When the BRK bit is set, the  
28 packet does not contain any async data (i.e., the Byte Count field  
29 contains a zero). Upon receipt of a general purpose async packet  
30 with BRK set, the FMC in the destination cluster flushes its output  
31 buffer for the destination port and generates a break on that port.

32      The MCS-II multidrop console data packet format is illustrated  
33 in Figure 15.

34      The packet can contain up to four bytes of async data. The  
35 four bytes are placed in bits 8 - 39 with the first byte in bits

1       8 - 15, the second in 16 - 23 and so on. The receiving FMC  
2       determines the actual number of data bytes in the packet by  
3       checking the Byte Count field (bits 45 - 47).

4       The Destination Cluster field (bits 48 - 55) contains the  
5       address of the MCS cluster for which the packet is ultimately  
6       intended. The contents of this field are only meaningful if the  
7       BRD bit is reset.

8       The Source Cluster field (bits 56 - 63) contains the address  
9       of the cluster in which the originating FMC resides. Because  
10      multiple packets are required to send a multidrop message, a FMC  
11      in a cluster may be receiving parts of messages from two or more  
12      clusters at the same time. The source cluster field in the packets  
13      allows the receiving FMC to segregate message pieces based on  
14      source cluster and thus properly reconstruct the messages.

15      The SOM bit (bit 64) indicates whether the async data in the  
16      packet represents the start of a multidrop message or not. If the  
17      SOM bit is set, the packet contains the first 1 - 4 bytes  
18      (depending on the Byte Count) of a multidrop message. If the SOM  
19      bit is reset, the packet contains data from within the body of a  
20      message.

21      The EOM bit (bit 65) indicates whether the async data in the  
22      packet represents the end of a multidrop message or not. If the  
23      EOM bit is set, the packet contains the last 1 - 4 bytes (depending  
24      on the Byte Count) of a multidrop message. If the EOM bit is  
25      reset, at least one more packet of data from the message will  
26      follow.

27      The BRD bit (bit 67) is set if the packet is to be broadcast  
28      throughout the FOMCS network to all clusters. If the BRD bit is  
29      set, all FMCs in a FOMCS hub will forward the packet to their  
30      respective remote clusters. All cluster FMCs receiving such a  
31      packet will accept it (assuming they have multidrop support  
32      enabled).

33      The interrupt packet format is shown in Figure 16.

34      The Destination Cluster field (bits 48 - 55) contains the  
35      address of the MCS cluster for which the packet is ultimately

1       intended. The FMC in the destination cluster uses the Destination  
2       Line field (bits 56 - 63) to determine which output interrupt line  
3       to pulse.

4       A Motorola 68000 microprocessor on the FMC provides the  
5       configuration system interface as well as data management for all  
6       transfers other than memory write transfers. This includes all  
7       asynchronous data, interrupts and error logging. It also provides  
8       diagnostic capabilities driven through the configuration  
9       programming interface.

10      Four Signetics 68681 DUARTs on the FMC provide support for  
11     the exchanges of async serial data between the nodes and/or devices  
12     in separate MCS clusters. The async support is designed in such  
13     a way that communicating entities need not be aware that the async  
14     data is actually traveling over a high-speed fiber or connection.  
15     From the perspective of the entities, communication is not  
16     functionally different from the case where the nodes and/or devices  
17     are directly connected via RS-232 cables. No special protocol  
18     information has to be inserted by the communicating entities into  
19     the async data stream to allow the data to move through the MCS  
20     network. Figure 17 illustrates the handling of async serial data  
21     by a FMC in a cluster.

22      As async serial data is received from a node or device, the  
23     FMC packetizes the data and transmits the packets over the high  
24     speed serial link. In addition to async data, each packet contains  
25     an address which facilitates routing of the packet through the MCS  
26     network. In the other direction, the FMC receives and decodes  
27     packets of async data from the high speed link. The address in the  
28     packet is discarded and the async data is passed to the node or  
29     device.

30      The address in an async packet is designed to allow routing  
31     of the packet through a MCS hub. To accomplish this, the address  
32     consists of two fields, a destination cluster field and a  
33     destination port field. The destination cluster field indicates  
34     the cluster to which the packet is to be routed. The destination  
35     port field indicates which async link of the FMC in the destination

1 cluster that the data is intended for. The destination FMC  
2 validates the address when it receives the packet. If the  
3 destination cluster address does not match the local cluster  
4 address, the packet is discarded.

5 The FMC maintains a list of eight async addresses, one for  
6 each general purpose async port. When async data is received from  
7 one of the eight ports, the FMC looks up the async address for that  
8 port and includes it in the packet(s) sent over the high speed  
9 link. Thus, there is a static connection between each general  
10 purpose async port of a FMC and an async port of a FMC in some  
11 other cluster.

12 The contents of the list of async addresses and the local  
13 cluster address are established during configuration programming  
14 of the FMC. The physical characteristics of the async links (i.e.,  
15 baud rate, character length, etc.) are also established during  
16 configuration programming.

17 In a MCS hub, the FMCs are programmed to operate in a special  
18 async data pass-through mode. This mode of operation is  
19 illustrated in Figure 18. Async packets received over the high  
20 speed link are decoded by the receiving FMC and sent over the hub  
21 MC bus to the other FMCs in the hub. The address field inserted  
22 by the FMC at the originating cluster is passed along over the hub  
23 MC bus as well as the async data. Each FMC in the hub which  
24 receives the address and async data from the MC bus compares the  
25 destination cluster field to the address of the cluster at the  
26 remote end of its high speed link. If a match occurs, the FMC  
27 builds and transmits an async packet over the high speed data link.

28 The remote cluster address used by a FMC in the hub to perform  
29 the routing function just mentioned is established during  
30 configuration programming. Since the async links of a FMC in a hub  
31 are not connected and are ignored by the FMC, no async address list  
32 or async link physical characteristics can be programmed.

33 To accommodate the case where the high speed link of a FMC in  
34 one hub is directly connected to a FMC in another hub (rather than  
35 to a MCS cluster), async address checking may also be disabled in

1       a FMC via configuration programming. Thus, all async packet  
2       traffic over the bus of one hub will also appear on the bus of the  
3       other hub.

4       The general purpose async ports of a FMC support hardware flow  
5       control using DTR and CTS. When a FMC wishes to transmit over a  
6       general purpose async port and hardware flow control is enabled  
7       for that port, the FMC only transmits as long as it sees CTS  
8       asserted. A loss of CTS during transmission causes the port to  
9       cease transmission until CTS reappears. Thus, the device connected  
10      to an FMC async port can throttle FMC data transmission for that  
11      port by asserting and deasserting CTS.

12      The FMC can also throttle a device which is sending it data  
13      over a general purpose async port assuming that an appropriate  
14      cable is used and the device pays attention to the CTS signal.  
15      When the FMC determines that its receive buffer for the port is  
16      nearly full, it deasserts DTR to inform the device connected to the  
17      port of the condition. Assuming a cable which connects the port's  
18      DTR signal to the device's CTS signal, the device will see a loss  
19      of CTS. This should cause the device to cease transmission until  
20      the FMC asserts DTR to indicate that more data can be accepted.

21      During configuration programming of the FMC, async flow  
22      control using DTR and CTS can be enabled or disabled on a per port  
23      basis. If DTR/CTS flow control is not desired, FMC general purpose  
24      async ports can be configured for XON/XOFF flow control or flow  
25      control can be disabled altogether.

26      To deal with the situation in which a FMC is connected to an  
27      async data source which is transmitting data much faster than the  
28      device connected to the destination FMC can accept it, an async  
29      flow control mechanism is also implemented between FMCs. An FMC  
30      can send flow control packets to throttle the transmission of async  
31      data packets by the FMC connected to the source of the async data.  
32      Flow control can be asserted on a per async port basis so that the  
33      flow of async packets for other async ports is unaffected.

34      The FMC supports 16 interrupt lines: eight input lines and  
35      eight output lines. The lines allow an interrupt pulse generated

1 by a node or device in one MCS cluster to be passed, in effect,  
2 across the MCS network to a node or device in another cluster. The  
3 pulse enters the FMC in the originating cluster via an input  
4 interrupt line, is passed across the MCS network as a packet and  
5 leaves the FMC in the destination cluster via an output interrupt  
6 line. As with async data, this is designed in such a way that the  
7 node need not be aware that the interrupt pulse is travelling over  
8 a high speed serial link and not actually directly connected.

9 An overview of interrupt passing for a FOMCS configuration is  
10 shown in Figure 19. The process involved in passing an interrupt  
11 across FOMCS is very similar to that used to pass async data. The  
12 FMC detects the pulse on the input interrupt line and constructs  
13 a special interrupt packet which is transmitted over the high speed  
14 link. The interrupt packet contains an address which facilitates  
15 routing through the FOMCS network. At the destination FMC, the  
16 packet is decoded and the address is used to determine which  
17 interrupt line should be pulsed.

18 As in the async case, the address in an interrupt packet  
19 consists of two fields. The destination cluster field identifies  
20 the cluster to which the packet is to be routed. The destination  
21 line field indicates which output interrupt line is to be pulsed.  
22 As with async packets, the destination FMC validates the cluster  
23 field of a received interrupt packet and discards the packet if the  
24 destination cluster does not match the local cluster address.

25 The FMC maintains a list of eight interrupt line addresses,  
26 one for each input interrupt line. When the FMC detects a pulse  
27 on one of the input interrupt lines, it looks up the line address  
28 and includes it in the packet sent over the high speed link. Thus,  
29 there is a static connection between each input interrupt line of  
30 a FMC and an output line of a FMC in some other cluster. The  
31 contents of the list of interrupt line addresses are established  
32 during configuration programming of the FMC.

33 In a FOMCS hub, the FMCs are programmed to operate in  
34 pass-through mode very similar to that described earlier for async  
35 data. Interrupt packets received over high speed link are

1 distributed over the MC bus to the other FMCs in the hub. Each FMC  
2 in the hub receives the interrupt line address from the MC bus and  
3 compares the cluster field to the address of the cluster at the  
4 remote end of its high speed link. If a match occurs, the FMC  
5 builds and transmits an interrupt packet over the high speed link.

6 The remote cluster address used by a FMC in the hub to perform  
7 the routing function just mentioned is established during  
8 configuration programming. Interrupt address checking can also be  
9 disabled in a FMC to accommodate the situation where hubs are  
10 directly connected. Since the interrupt lines of a FMC in a hub  
11 are not connected and are ignored by the FMC, no input interrupt  
12 address list can be programmed.

13 One channel of a Signetics 68681 DUART on the FMC is used to  
14 provide support for the MCS-II multidrop console link. (The other  
15 channel of this DUART is used for the configuration programming  
16 link.) The FMC behaves basically as a gateway to allow console  
17 traffic to flow between nodes in separate MCS-II clusters. In each  
18 cluster, the FMC intercepts messages intended for remote nodes and  
19 transmits them as packets to the FMCs in the appropriate clusters.  
20 The FMCs receiving the packets decode them and send the messages  
21 to the destination nodes. The fact that this is happening is  
22 essentially transparent to the nodes. An example of a FOMCS  
23 network linking clusters of MCS-II nodes appears in Figure 20.

24 In the MCS-II multidrop console environment, one of the drops  
25 acts as the master and all others are slaves. Only the master can  
26 initiate message exchanges on the multidrop link; a slave can only  
27 transmit after receiving a poll message from the master. The FMC  
28 in a cluster assumes that there is a local master in the cluster.  
29 When the FMC receives a message addressed to a remote node, it  
30 transmits the message as one or more packets over its high speed  
31 serial link; when the FMC receives one or more packets from the  
32 high speed link containing a message from a remote node, it buffers  
33 the message until it is polled by the master. Then, the FMC  
34 transmits the saved message over the local multidrop link. Note  
35 that a cluster FMC's slave address on the multidrop link is its MC

1 bus node id.

2       The handling of multidrop message data in the FOMCS network  
3 is basically the same as that for general purpose async data and  
4 interrupts. Multidrop data is routed through the FOMCS network in  
5 special packets. Each multidrop data packet contains a destination  
6 cluster address (which is validated by the destination FMC) and  
7 part of a message. Unlike interrupt packets or packets of general  
8 purpose async data, multidrop message packets also contain a source  
9 cluster address. The receiving FMC uses the source address to  
10 segregate pieces of messages from different clusters into different  
11 buffers.

12      The source cluster address which a node inserts into a  
13 message is supplied by the FMC in the cluster. The multidrop  
14 master periodically sends a request-cluster-address message to the  
15 FMC which causes it to broadcast a response message containing the  
16 cluster address to all nodes in the cluster. This cluster address  
17 is the address established during configuration programming via the  
18 Define Cluster Address command. Note that in a MCS-II cluster  
19 where there is no FMC to supply the source cluster.  
20 communication between nodes is unaffected because the source  
21 cluster address field is not included in messages exchanged by  
22 nodes in the same cluster.

23      In FOMCS configurations where a hub is present, multidrop  
24 data is routed from the receiving FMC to the other FMCs in the hub  
25 via the hub MC bus. Packets are then built and transmitted from  
26 FMCs in the hub to the FMCs in the destination clusters. As with  
27 general purpose async and interrupts, a FMC in the hub looks at the  
28 destination cluster address to determine if it should build and  
29 transmit a packet over its high speed link. If the destination  
30 cluster matches the address of the cluster connected to the FMC's  
31 serial data link, the FMC forwards the multidrop data.

32      The MCS-II multidrop broadcast capability is also supported  
33 by FOMCS. When the FMC in a cluster receives a message over the  
34 local multidrop link that is to be broadcast to all nodes, it sends  
35 the message across its high speed link in packets which have a

1 broadcast flag set. FMCs in a hub will always forward such packets  
2 regardless of the contents of the destination cluster field. All  
3 cluster FMCs receiving the broadcast message will transmit it over  
4 their local multidrop links when polled by the local masters.

5 During configuration programming, a cluster FMC is programmed  
6 with a list of remote cluster addresses. When multidrop support  
7 is enabled, the FMC intercepts any message on the multidrop link  
8 which is addressed to a node in one of the clusters in the list.  
9 The local multidrop master can obtain the list from the FMC by  
10 sending it an inquiry message. The FMC responds by encoding the  
11 list into a remote-cluster-list message which it sends over the  
12 multidrop link.

13 The FMC supports an optional configuration which allows  
14 automatic failover to a secondary high speed serial link should the  
15 primary link go down. This high availability feature is  
16 illustrated in Figure 21.

17 The secondary FMCs in each cluster monitor the health of the  
18 primary FMCs. Each secondary FMC is configured for the same MC bus  
19 node id as the primary it monitors but the secondaries do not  
20 interact on the MC bus as long as the primaries are healthy. In  
21 other words, all memory write traffic between the clusters goes  
22 over the primary high speed link until a failure occurs. Likewise,  
23 all other types of packet traffic (i.e., async, interrupt, etc.)  
24 go over the primary link until a failure is detected.

25 To keep the secondary FMCs informed as to their health, the  
26 primaries periodically send their respective secondaries an "I'm  
27 okay" indication via a health-check link. The UART of a Motorola  
28 68901 MFP on the FMC is used to implement the health-check link.  
29 The primaries also periodically exchange test packets to determine  
30 if the primary link is still functioning.

31 If a secondary FMC does not receive an "I'm okay" indication  
32 within a specified time period since the last indication or if the  
33 secondary receives a link failure indication from the primary, the  
34 secondary initiates the fail-over process by: 1) forcing the  
35 primary FMC to cease operation, and 2) sending a failure-detected

1      packet to the secondary in the remote cluster. The remote  
2      secondary FMC then forces its primary FMC to cease operation. The  
3      remote secondary then sends a fail-over-complete packet back to  
4      the secondary which detected the failure. Subsequent communication  
5      between the clusters occurs over the secondary high speed link.

6      A secondary FMC forces a primary to cease operation by  
7      asserting a special additional signal which is included in the  
8      health-check link cable connecting the primary and secondary. When  
9      asserted this signal places the primary FMC into a  
10     hardware-controlled offline state. In this state, all I/O  
11    interfaces on the FMC are disabled so that the FMC is unable to  
12    assert any signals on the MC bus, transmit over the high speed  
13    link, transmit over any of its sync links or pulse any of its  
14    output interrupt lines. The effect is identical to that achieved  
15    by putting the FMC online/offline switch into the offline position.

16     The (old) primary FMC is held in this offline state until the  
17    secondary FMC (which is the new primary) is reset via a power  
18    cycle, hardware reset or a received Reset command.

19     While the old primary FMC is being held in this offline state,  
20    it monitors the health-check link (if it is operational enough to  
21    do so) for the receipt of "I'm okay" characters from the new  
22    primary. If the old primary receives such characters, it  
23    reconfigures itself to assume the secondary role. Thus, when an  
24    attempt is made to return the old primary FMC to an online state,  
25    it behaves as a secondary and remains in a (firmware-controlled)  
26    offline state. This prevents the old primary from contending with  
27    the new primary on the MC bus.

28     The fail-over process can also be initiated manually via  
29    the configuration programming link. To cause a fail-over, a  
30    command is sent over the programming link to one of the secondary  
31    FMCs. The fail-over proceeds as described above and when it is  
32    complete, a response indicating such is returned via the  
33    programming link.

34     While the previous discussion relates to high availability  
35    of the high speed link between clusters, the high availability

1       feature can be extended to the hub in a FOMCS star network. High  
2 availability in a hub is achieved by having a secondary FMC for  
3 each primary FMC in the hub. Thus, each cluster is connected to  
4 the hub by two high speed links, a primary and a secondary.  
5 Fail-over to a secondary link is essentially the same as the  
6 cluster to cluster case.

7       Note that to really achieve high availability in a cluster,  
8 nodes which have async or interrupt connections to the primary  
9 FMC must have a redundant set of connections to the secondary.  
10 When the secondary FMC takes over, the nodes must switch over to  
11 the secondary async and interrupt connections. To facilitate this  
12 process, one of the output interrupt lines of a secondary FMC can  
13 be used to inform the node(s) that fail-over has occurred. During  
14 configuration programming of a secondary FMC, an output interrupt  
15 line can be designated for this purpose.

16      The fail-over process is not automatically reversible.  
17 Once the secondary FMCs have taken over, they become in effect the  
18 primaries. When the previous primary FMCs and/or high speed link  
19 are repaired, they must be programmed to behave as the secondaries  
20 (if they have not already reconfigured themselves as secondaries).

21      Configuration of a FMC as a primary or secondary occurs  
22 during configuration programming. The maximum time period that a  
23 secondary will allow between "I'm okay" indications from the  
24 primary is also established. The high availability feature can  
25 also be disabled altogether.

26      Another usage of the microprocessor is to allow diagnosis  
27 of an individual FMC and/or high speed serial link without  
28 bringing the entire MCS network offline. This capability is  
29 particularly useful in the star network environment where it is  
30 undesirable to shut down the entire hub just to diagnose a problem  
31 between the hub and a particular cluster. If the problem turns out  
32 to be the high speed link or the FMC in the cluster, it can be  
33 corrected without taking down the entire hub. Of course, software  
34 resynchronization will probably be necessary between the affected  
35 cluster and the other clusters it was communicating with but the

1 rest of the clusters connected to the hub can continue to  
2 communicate without interruption.

3 Special operational modes, referred to as hub diagnostic and  
4 cluster diagnostic modes, are available to allow the FMC to be  
5 isolated from the high speed coax or fiber link for testing  
6 purposes. In these modes, the FMC operation is identical to normal  
7 hub or cluster mode except that the output of the Gazelle Hot Rod  
8 Tx chip is directly connected to the input of the Rx chip. To  
9 configure the FMC to operate in hub or cluster diagnostic mode, the  
10 Set FMC Online/Offline command used to place the FMC in a  
11 firmware-controlled offline state. Then, the desired mode is  
12 selected via the Set Operational Mode command and the FMC is  
13 returned to an online state by means of a second Set FMC  
14 Online/Offline command.

15 Individual functional areas of the FMC can be tested by  
16 sending Specify Diagnostic Loopback Data commands to the FMC.  
17 Variations of the Specify Diagnostic Loopback Data command can be  
18 used to invoke memory write transfer loopback, async data loopback  
19 and interrupt loopback. A FMC will only accept such commands when  
20 in the firmware-controlled offline state.

21 The FMC supports three diagnostic loopback modes for memory  
22 write transfers: internal, external and MC bus loopback. Internal  
23 loopback loops data through the FMC from the MC bus input latch to  
24 the MC bus output latch. External loopback tests the same path  
25 except that the data is actually transmitted over the high speed  
26 serial link and looped back via an external loopback cable  
27 connection. Internal loopback mode is shown in Figure 22.  
28 External loopback mode is shown in Figure 23. MC bus loopback  
29 loops data from the MC bus output latch to the MC bus input latch  
30 via the MC bus. This loopback mode is illustrated in Figure 24.

31 Note that when internal or external loopback is performed,  
32 the FMC hit/translation RAM must also be programmed appropriately  
33 to achieve the desired effect. Loopback modes can be used to  
34 specifically test reflection region or address translation logic  
35 or the hit/translation RAM can be programmed such that all regions

1 are reflected and address translation does not actually do anything  
2 (i.e., the original address and the translated address are the  
3 same).

4 In internal loopback mode, the MC bus interface of the FMC  
5 is disabled and the Gazelle Hot Rod chips are configured such that  
6 the serial output of the transmitter chip is connected directly to  
7 the serial input of the receiver chip. The Specify Diagnostic  
8 Loopback Data command which initiated the loopback also contains  
9 an address and data pattern to be looped through the FMC hardware.  
10 The FMC inserts the address and data pattern into the MC bus input  
11 latch. The address and data proceed through the Tx path and at  
12 the end of the Tx path are transmitted serially in a packet. The  
13 Packet is looped back through the Rx path and the address and data  
14 end up in the MC bus output latch. The FMC removes the address and  
15 data from the latch and includes them in the response sent back  
16 via the programming link.

17 In external loopback mode, the MC bus interface of the FMC  
18 is disabled. Again, the Specify Diagnostic Loopback Data command  
19 which initiated the loopback contains an address and data pattern  
20 to be looped through the FMC hardware and the external loopback  
21 connection. The FMC inserts the address and data pattern into the  
22 MC bus input latch. The address and data proceed through the Tx  
23 path and at the end of the Tx path are transmitted serially in a  
24 packet. The packet is looped through the external loopback  
25 connection, received again by the FMC and moves through the Rx path  
26 to the MC bus output latch. A response is sent back via the  
27 programming link containing the address and data pattern read from  
28 the latch.

29 In MC bus loopback mode, the high speed serial link interface  
30 is disabled and the MC bus interface of the FMC is enabled but  
31 functions somewhat differently from normal. To perform the MC bus  
32 loopback, the FMC inserts the address and data pattern from the  
33 Specify Diagnostic Loopback Data command into the MC bus output  
34 latch. The FMC MC bus interface hardware then requests the bus and  
35 when it receives a grant, generates a transfer on the MC bus with

1       the data valid signal deasserted. This causes any nodes on the bus  
2       to ignore the transfer. The FMC MC bus interface hardware,  
3       however, is configured to receive its own transfer. The looped  
4       data is read from the MC bus input latch and returned in the  
5       response sent back via the programming link.

6       The FMC supports three diagnostic loopback modes for general  
7       purpose async data: internal, external, and port-port. The three  
8       varieties are illustrated in Figure 25. The FMC performs the  
9       requested async loopback as the result of a Specify Diagnostic  
10      Loopback Data command received over the configuration programming  
11      link.

12      The Specify Diagnostic Loopback Data command informs the FMC  
13      as to which async port(s) will participate in the loopback test and  
14      provides the data to be looped. If an async port is selected for  
15      internal loopback, the FMC initializes the port hardware to wrap  
16      transmitted data back to the receive side of the port. The FMC  
17      then causes the port to transmit the data. If the port is  
18      functioning correctly, the FMC immediately receives the data back  
19      again. The received data is passed back over the programming link  
20      in the command response. If no data is received, the FMC returns  
21      a response indicating such.

22      External loopback requires that a loopback plug be connected  
23      to the port which wraps transmitted data back to the receive pin  
24      of the port. The FMC initializes the port hardware for normal  
25      operation and transmits the data via the specified port. Again,  
26      the data should be immediately received from the same port. The  
27      response to the command contains the received data or indicates  
28      failure of the loopback operation.

29      Port-port loopback requires that a RS-232 cable connect the  
30      two selected ports. The FMC initializes the ports for normal  
31      operation and transmits the data via the port specified in the  
32      Specify Diagnostic Loopback Data command. The response to the  
33      command contains the data received from the other port or indicates  
34      failure of the loopback operation.

35      The FMC supports external loopback for the interrupt lines.

1       A Specify Diagnostic Loopback Data command to the FMC selects a  
2 pair of interrupt lines that will participate in the loopback, one  
3 input and one output. Note that loopback requires that a wire  
4 connect the selected interrupt lines. To perform the loopback,  
5 the FMC generates a pulse on the output line of the pair and  
6 reports in its command response whether or not a pulse was detected  
7 on the input line.

8       The FMC supports two diagnostic loopback modes for the MCS-II  
9 multidrop console link: internal and external. Internal loopback  
10 is performed exactly as with the general purpose async ports.  
11 External loopback is functionally identical to the method used with  
12 the general purpose async ports, but because of the unique nature  
13 of the multidrop link, no external loopback cable is required.  
14 However, the external loopback test will drive the multidrop link.  
15 Therefore, if testing is desired without bringing the entire  
16 multidrop link offline, the MCS cable which carries the multidrop  
17 link should be unplugged from the FMC chassis backplane prior to  
18 initiating diagnostic tests and replaced when testing is concluded.

19       The FMC supports two diagnostic loopback modes for the high  
20 availability health-check link: internal and external. Both modes  
21 are performed in the same manner as with the general purpose async  
22 ports.

23       Each packet transferred across the high speed serial link in  
24 a FOMCS configuration contains an error detection code (EDC) which  
25 allows the receiving FMC to determine if an error occurred during  
26 transmission. Packets received with good EDC are also checked for  
27 illegal or illogical bit settings. Parity is checked for transfers  
28 received across the MC bus and transfers received with good parity  
29 are also checked for illegal or illogical bit settings.

30       For packet errors and transfer errors detected by the  
31 receiving FMC, the FOMCS philosophy is to report the error to the  
32 node(s) in the nearest cluster rather than reporting the error to  
33 all nodes in the network. No attempt is made to handle errors in  
34 memory write transfer packets differently from errors detected in  
35 other types of packets because once an error is detected in a

1 packet, the entire contents of the packet are suspect including the  
2 packet type field.

3 The method of reporting errors is illustrated in Figures 26  
4 and 27. When a FMC in a cluster detects an error in a packet  
5 received over the high speed link or detects an error in a MC bus  
6 transfer, it reports the error to the node(s) in the cluster by:  
7 1) forcing a parity error on the MC bus and/or 2) directly  
8 interrupting the node(s). To force a parity error, the FMC  
9 arbitrates for the MC bus and when granted access, generates a  
10 transfer where the parity driven on the bus does not match the  
11 address and data. This causes the MC port of the each node to  
12 detect a transfer with bad parity and (hopefully) report it to the  
13 node via a parity error interrupt. The direct interrupt approach  
14 utilizes one or more of the FMC's eight output interrupt lines.

15 When a FMC in a hub detects an error in a transfer received  
16 over the hub MC bus or detects an error in a packet received over  
17 its high speed link, it builds an error packet and transmits it to  
18 the FMC at the other end of the high speed link. Receipt of the  
19 error packet causes the FMC in the cluster to report the error as  
20 described earlier. Note that whether or not the FMC in the cluster  
21 receives the packet correctly, an error will be reported.

22 To assist with diagnosis of packet transmission or MC bus  
23 transfer errors, the FMC keeps a copy of the last bad packet (if  
24 any) and the last bad MC bus transfer (if any) that it received.  
25 These copies can be accessed at any time via the configuration  
26 programming link.

27 During configuration programming, the error reporting  
28 behavior of a FMC in a cluster is established. The FMC can be  
29 programmed to report errors by generating MC bus parity errors  
30 and/or by generating interrupts. If the interrupt approach is  
31 selected, one or more output interrupt lines of the FMC can be  
32 programmed as outputs for error signals. Each of the selected  
33 lines can be further qualified as to when the line is pulsed: 1)  
34 when a bad MC bus transfer is detected (or when an error packet is  
35 received indicating that the remote FMC detected a bad transfer),

1        2) when a bad packet is received over the high speed link (or when  
2        an error packet is received indicating that the remote FMC detected  
3        a bad packet), or 3) when either a bad transfer or a bad packet is  
4        detected.

5        Although the present invention has been shown and described  
6        with reference to preferred embodiments, changes and modifications  
7        are possible to those skilled in the art which do not depart from  
8        the spirit and contemplation of the inventive concepts taught  
9        herein. Such are deemed to fall within the purview of the  
10      invention as claimed.

We claim:

1. A system comprising:
  - a first and second set of plurality of nodes;
  - a first data bus associated with and connecting said first set of plurality of nodes;
  - a second data bus associated with and connecting said second set of plurality of nodes;
  - each node of said sets of plurality of nodes including a processing unit, a memory, a bus coupled to the processing unit and memory, and a sensor means for sensing a write to the memory and for transmitting the sensed write on said associated data bus;
  - first converter means connected to the first data bus for converting data on said first data bus to corresponding optical signals and received optical signals to corresponding data for transmission on said first data bus;
  - second converter means connected to the second data bus for converting data on said second data bus to corresponding optical signals and received optical signals to corresponding data for transmission on said second data bus; and
  - fiber optic means for optically transmitting data from one converter means to the other converter means.
2. The system of claim 1 wherein each said converter means includes conversion means for converting parallel data to serial optical signals and vice versa.
3. The system of claim 1 wherein each said converter means includes a FIFO for temporarily storing data.
4. The system of claim 1 wherein each node further includes I/O means for introducing I/O data into memory and wherein said sensor means responsive to a write to memory of I/O data transmits same on said associated data bus.
5. A system for connecting memory coupled systems, comprising:

a plurality of nodes;  
a first data bus connecting a first group of said plurality of nodes;  
a second data bus connecting a second group of said plurality of nodes;  
first converter means connected to the first data bus;  
second converter means connected to the second data bus;  
first fiber optic means for carrying transmitting data from the first converter means to the second converter means;  
second fiber optic means for carrying transmitted data from the second converter means to the first converter means;  
the first and second converter means each comprising:  
input latch means for receiving data from a respective data bus;  
hit and translation RAM means connected to the input latch means for determining the destination of data received from the data bus;  
first micro-interface means connected to the input latch means for controlling the hit and translation RAM means;  
transmission FIFO means connected to the input latch means for latching the data received from the data bus;  
error detection means for determining if an error exists in the data in the transmission FIFO means;  
first and second transmission latches connected to the transmission FIFO means;  
transmitter means connected to the first and second transmission latches for transmitting the data to another converter means;  
receiver means for receiving data transmitted from another converter means;  
first and second receiver latches for latching the received data;  
error detection means connected to the first and second latch means for checking if an error exists in the received data;  
second micro interface means for testing the received

data if the check by the error detection means fails;  
receive FIFO means connected to the first and second receive latch means for holding the received data after checking by the error detection means;  
output latch means for transmitting the received data to the respective data bus.

6. A system as claimed in Claim 5, further comprising first and second backup controllers for transmitting data between memory coupled systems upon a determination the first and second controllers are not working properly.

7. A system as claimed in Claim 6, wherein said input, output, transmit and receive latches of each of said plurality of controllers are able to be accessed in both a parallel and serial fashion.

8. A system as claimed in claim 1, wherein data is transmitted through the optical fiber means in 80 bit data frames.

9. A method comprising the steps of:  
establishing first and second data links;  
establishing first and second sets of nodes, each node including a processing unit, a memory, a bus coupled to the processing unit and memory and a sensing means for sensing a write to memory;  
sensing a write to a memory in one of said nodes of said first set;  
transmitting said sensed write on said first data link; and  
sensing the sensed write transmitted on said first data link and optically transmitting same to a remote point whereupon it is transmitted on said second data link to the memory of one of the nodes of said second set without intervention of the processing unit of said one node of said second set.

10. The method of claim 9 comprising the further steps of:
  - writing I/O data from an I/O source into the memory of a node in one of the sets of nodes;
  - sensing the written I/O data and transmitting same on the data link associated with said node; and
  - optically transmitting the written I/O data to a memory in a node of the other sets of nodes via its associated data link.

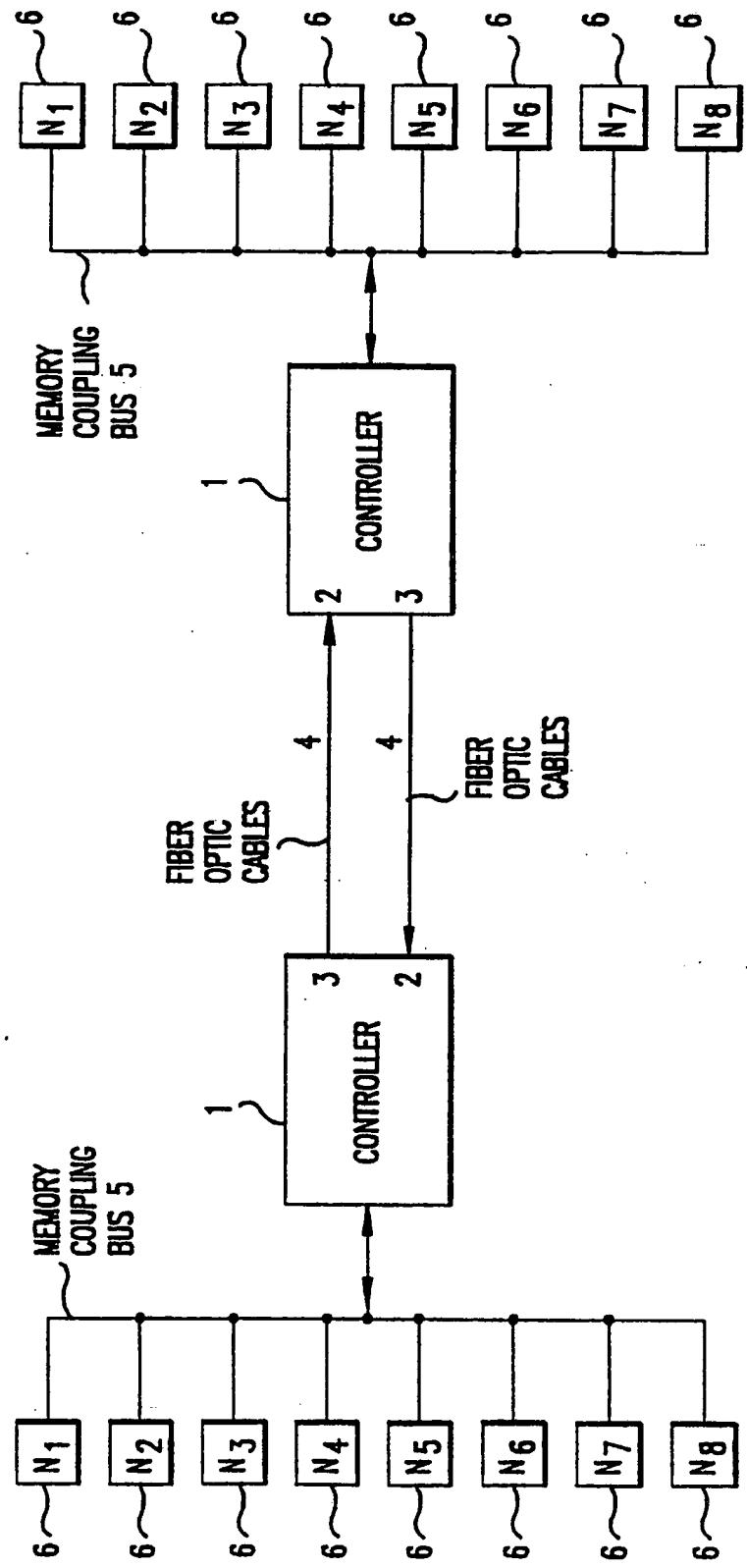


FIG.1

2 / 31

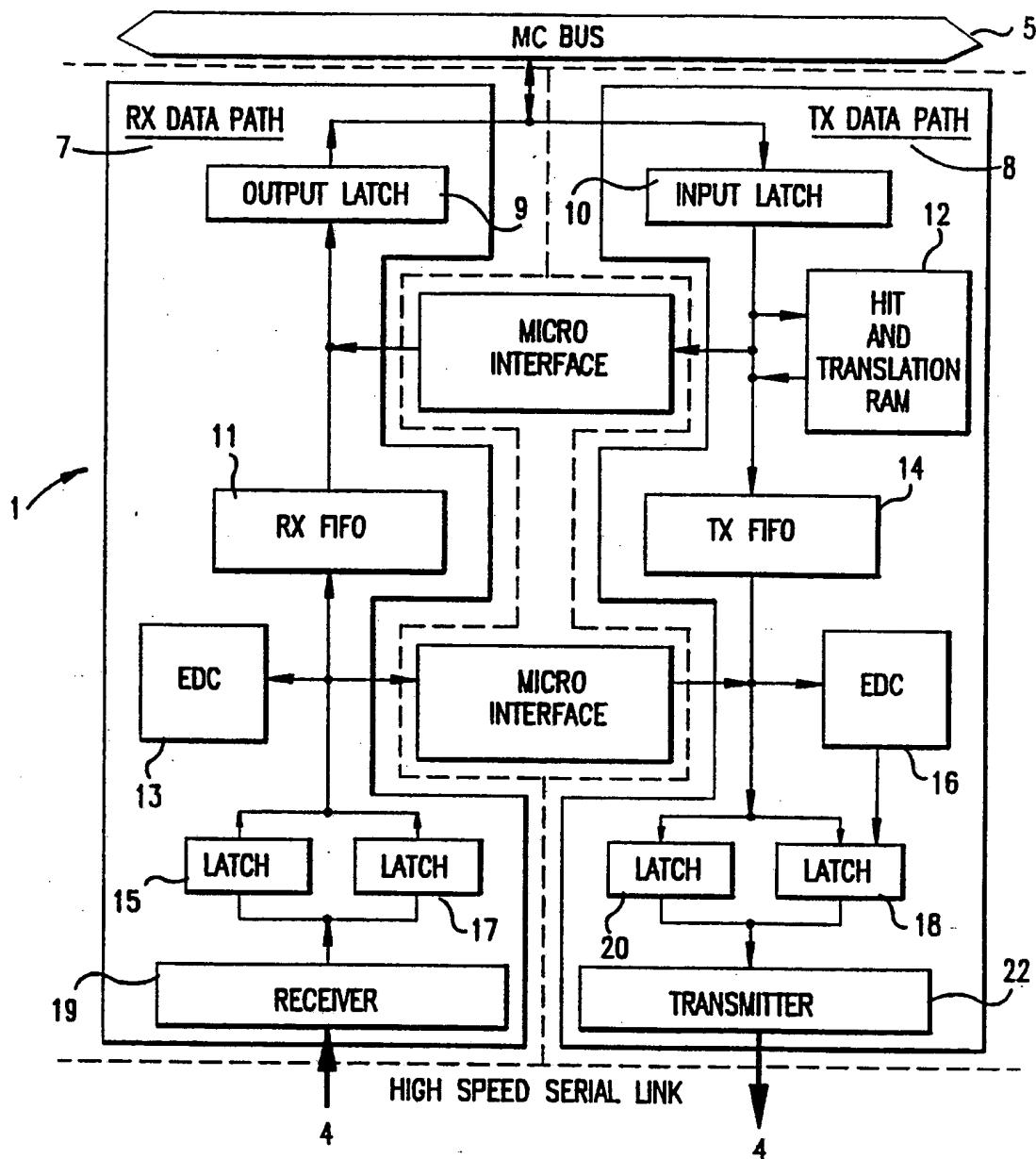


FIG.2

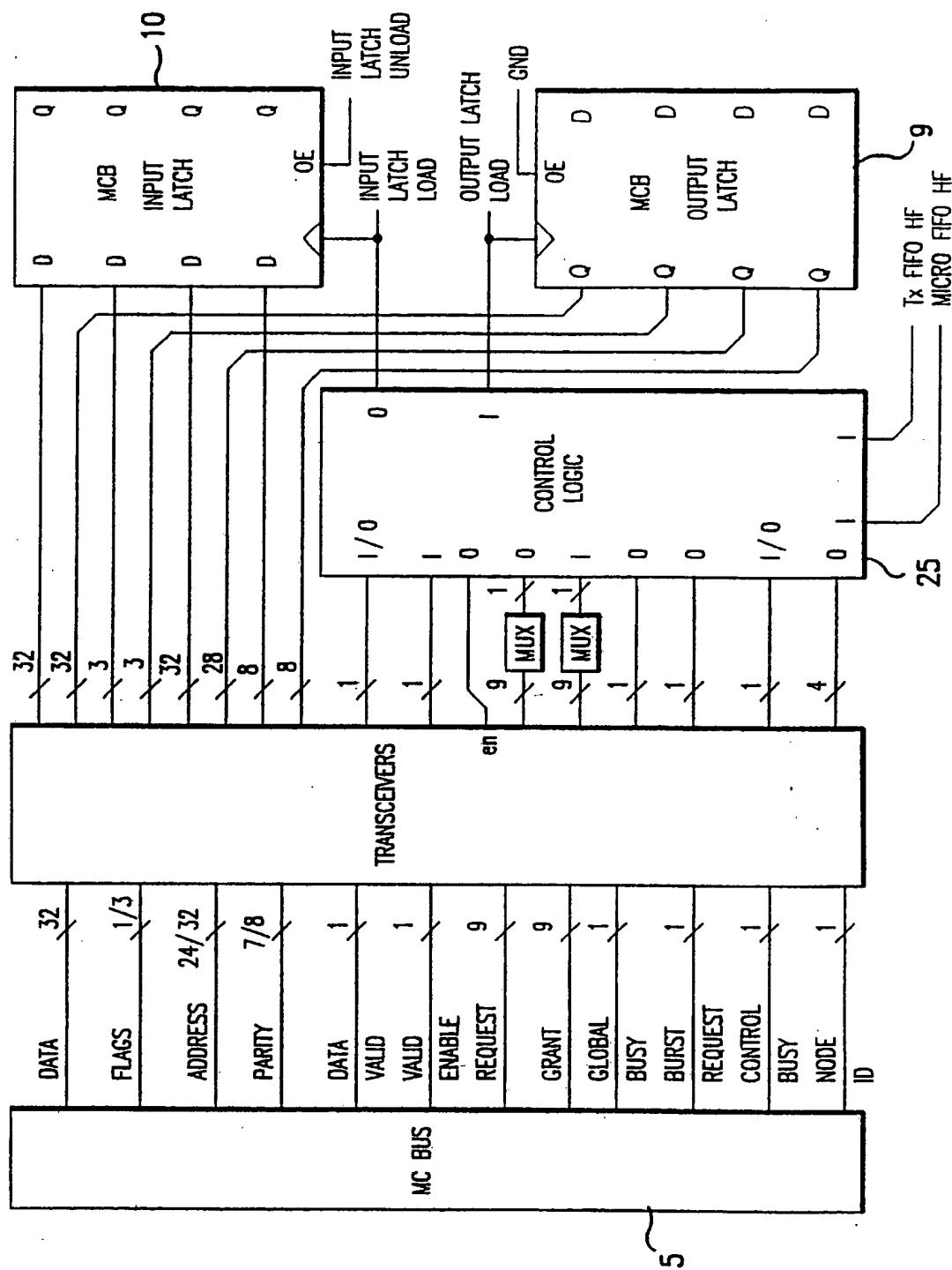


FIG.3

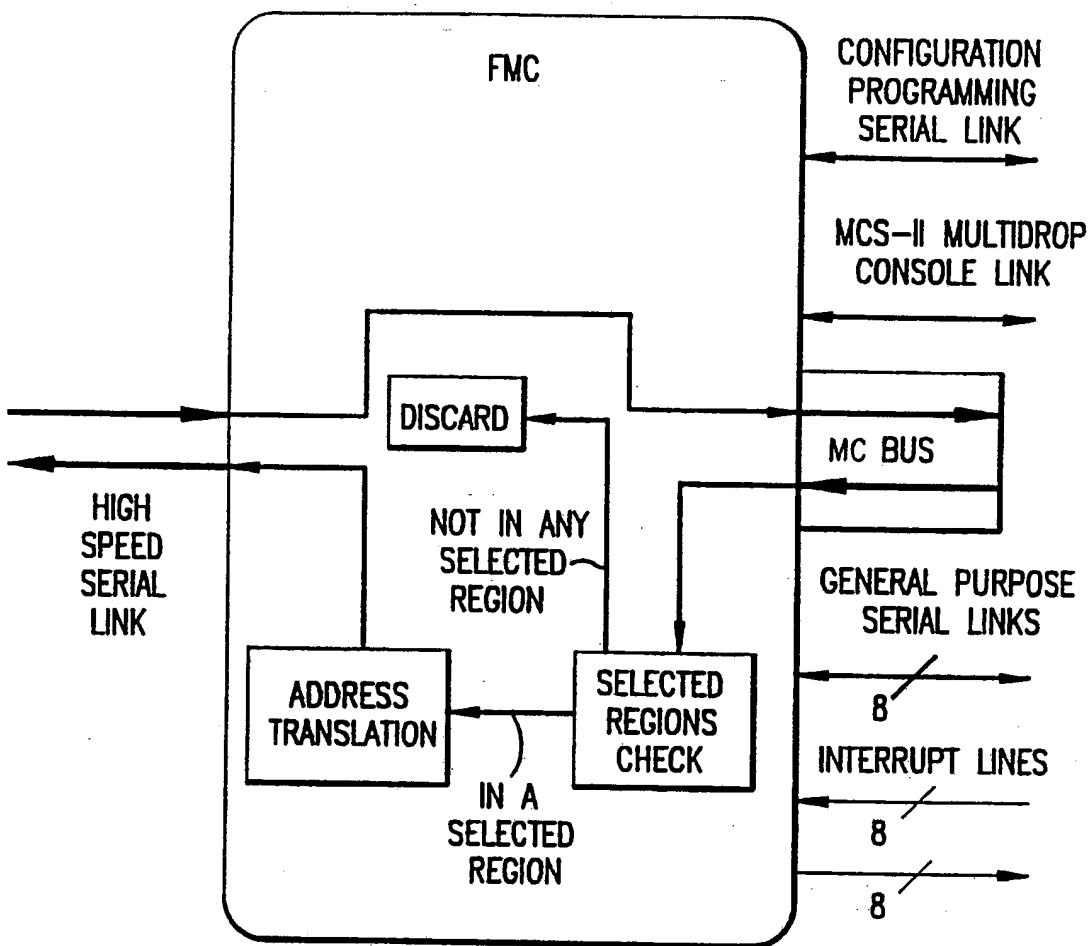
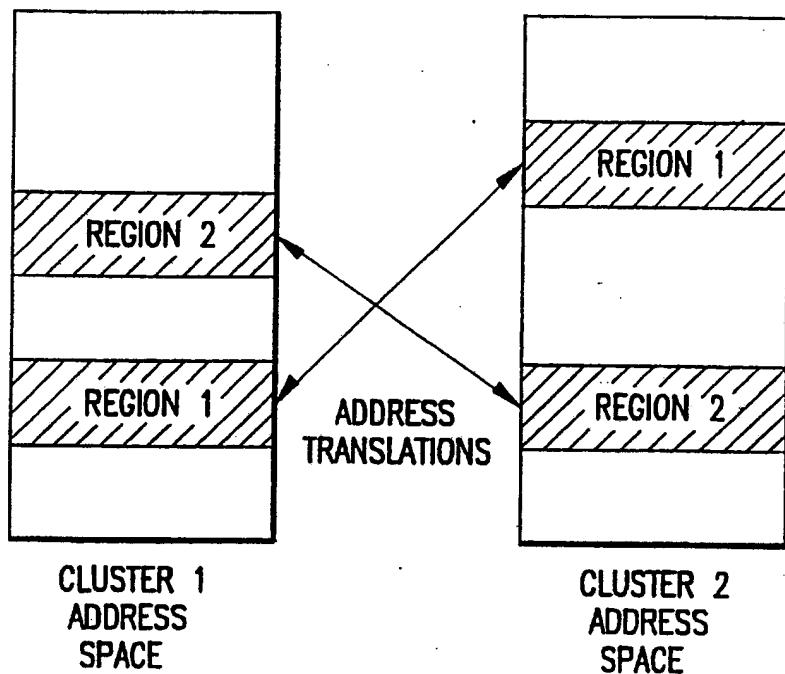


FIG.4

5 / 31



(NOTE THAT ONLY THE SHADED  
REGIONS IN EACH CLUSTER ARE  
REFLECTED OVER FIBER.)

FIG.5

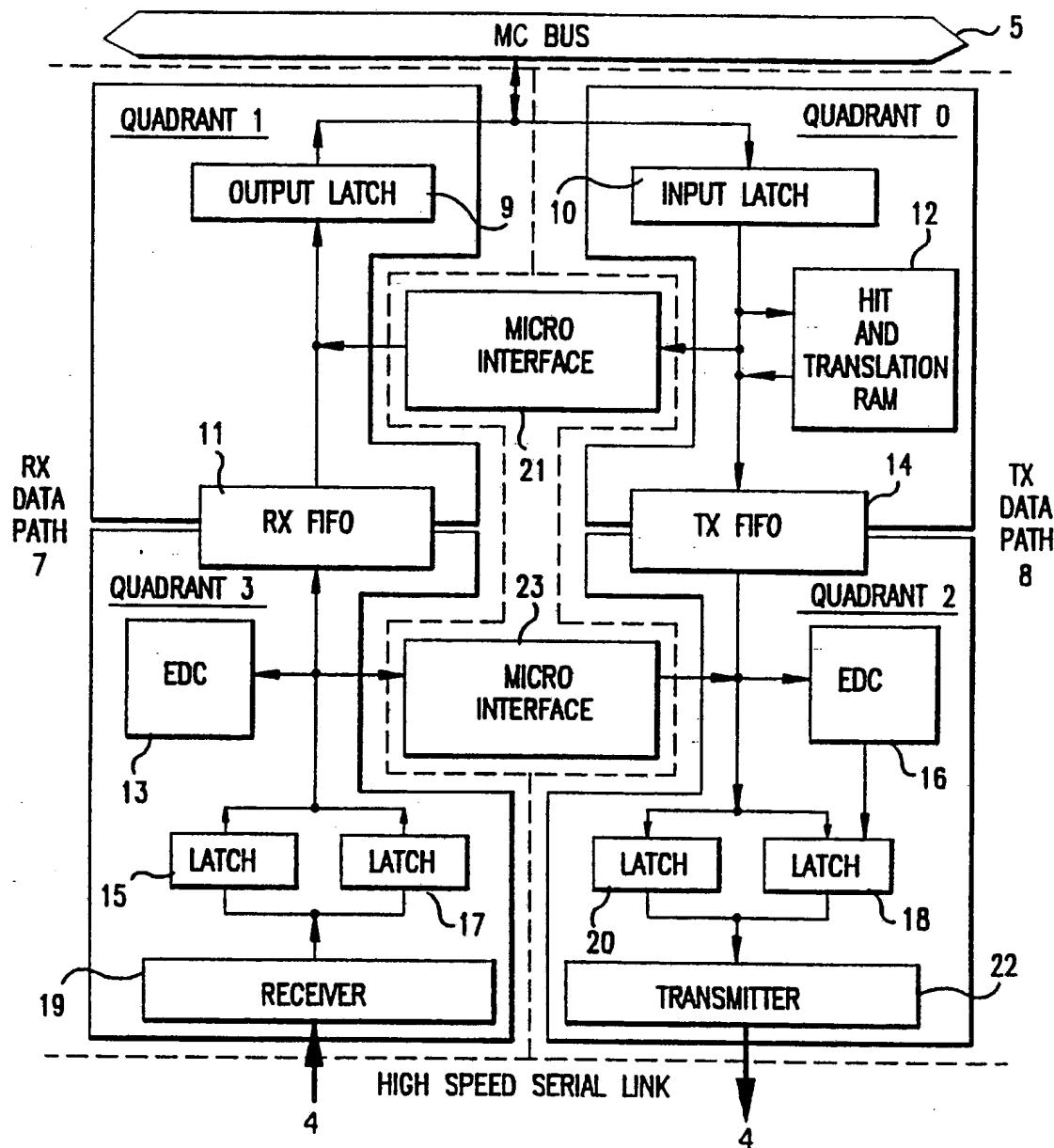


FIG.6

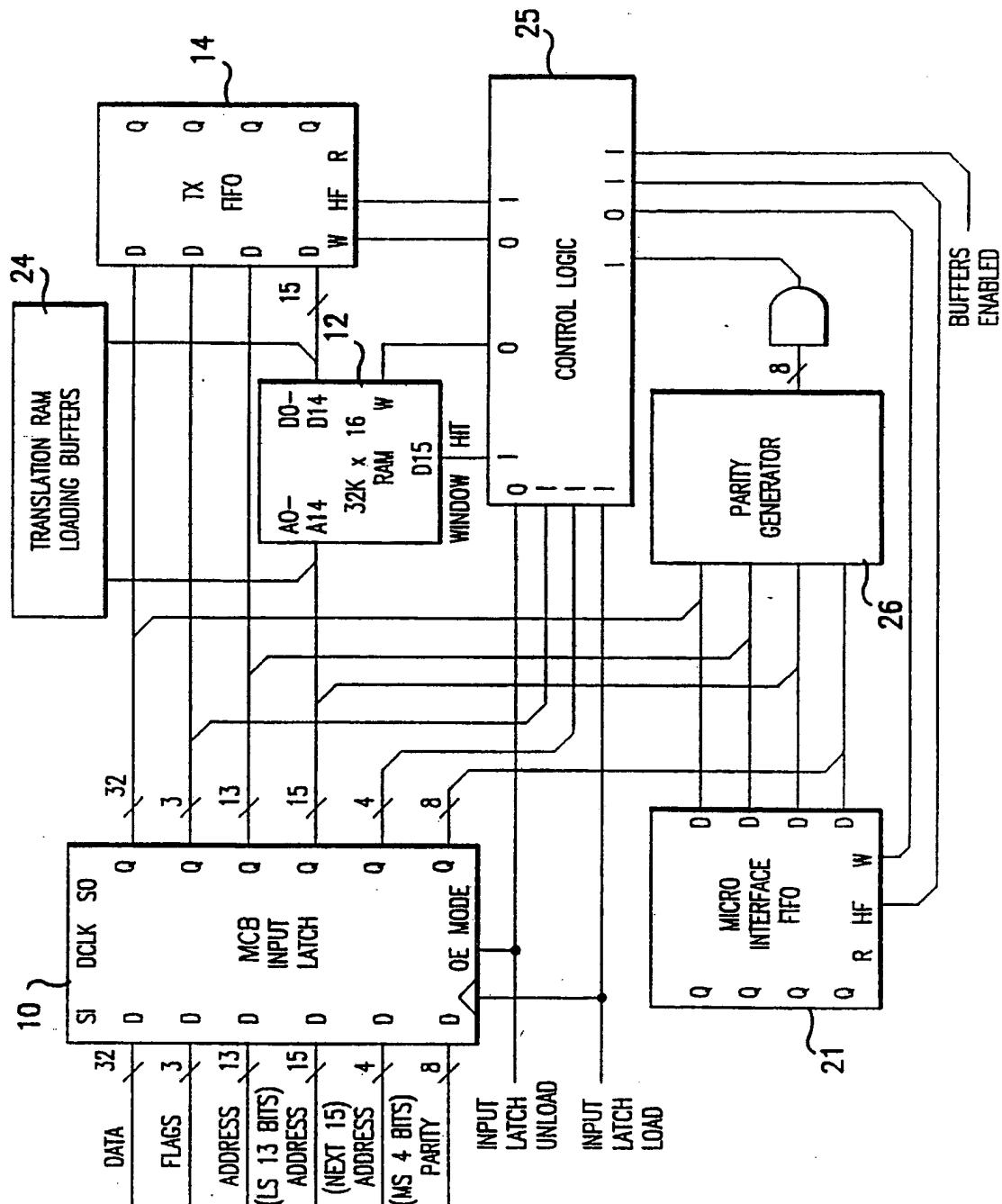


FIG. 7

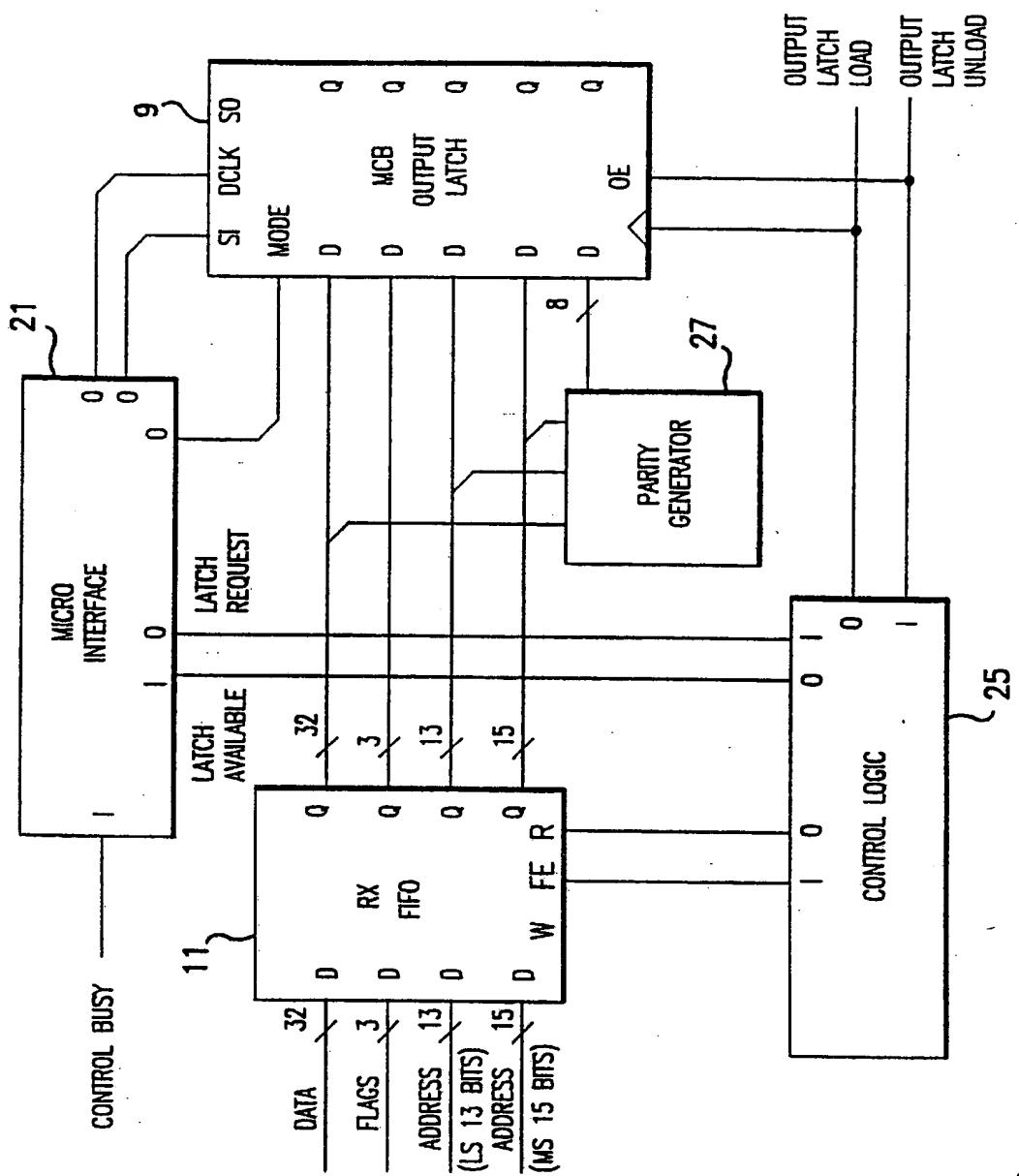


FIG.8

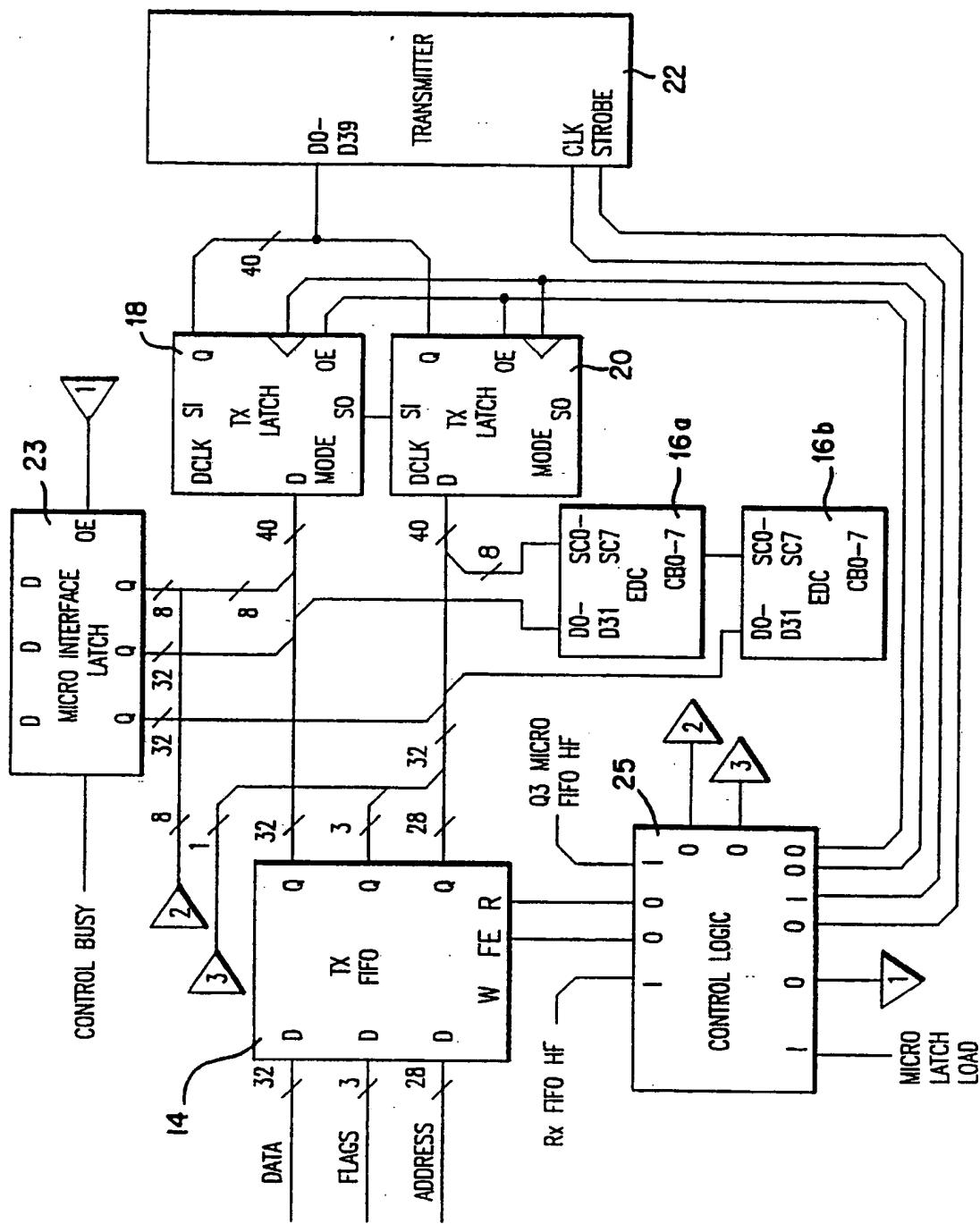


FIG. 9

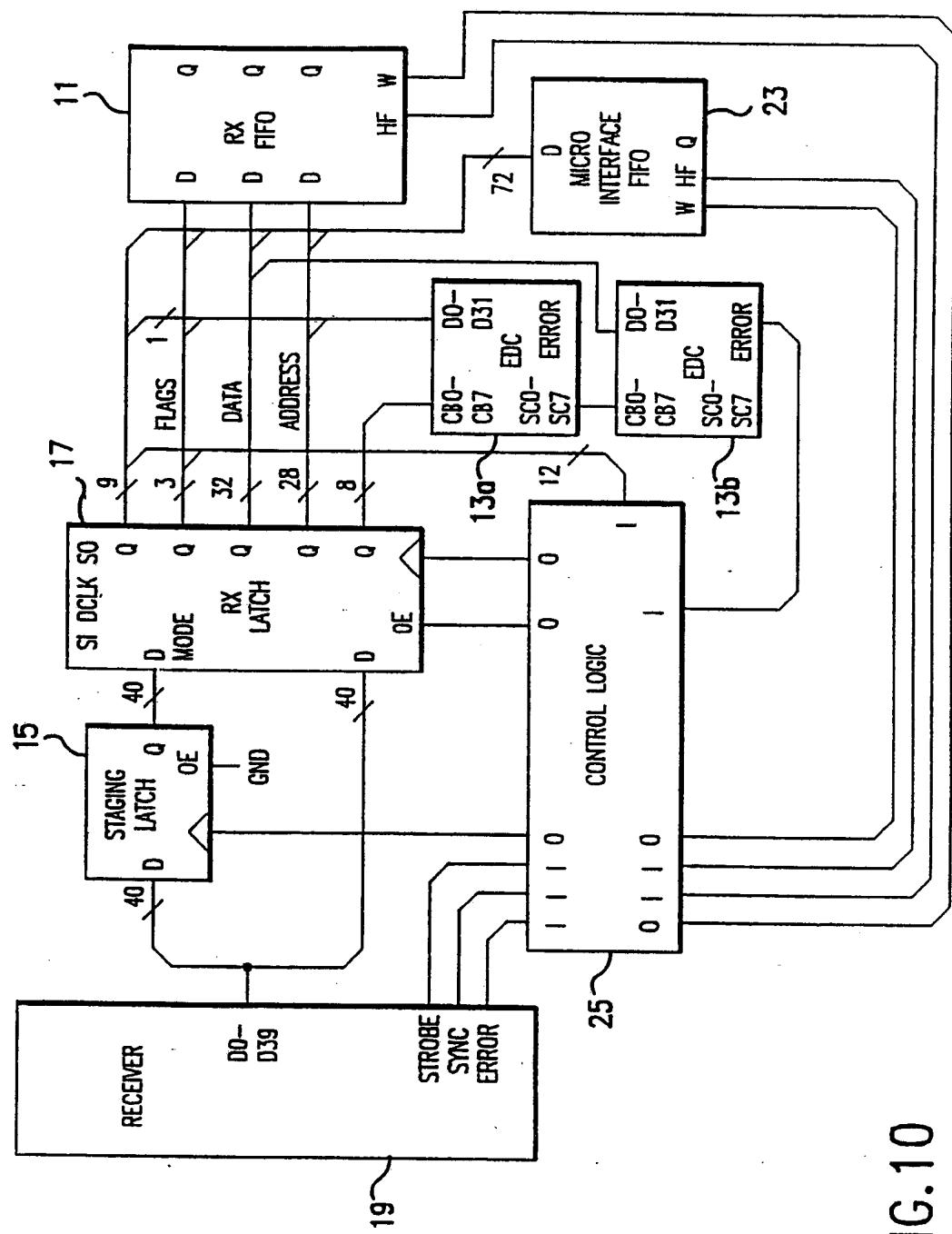


FIG. 10

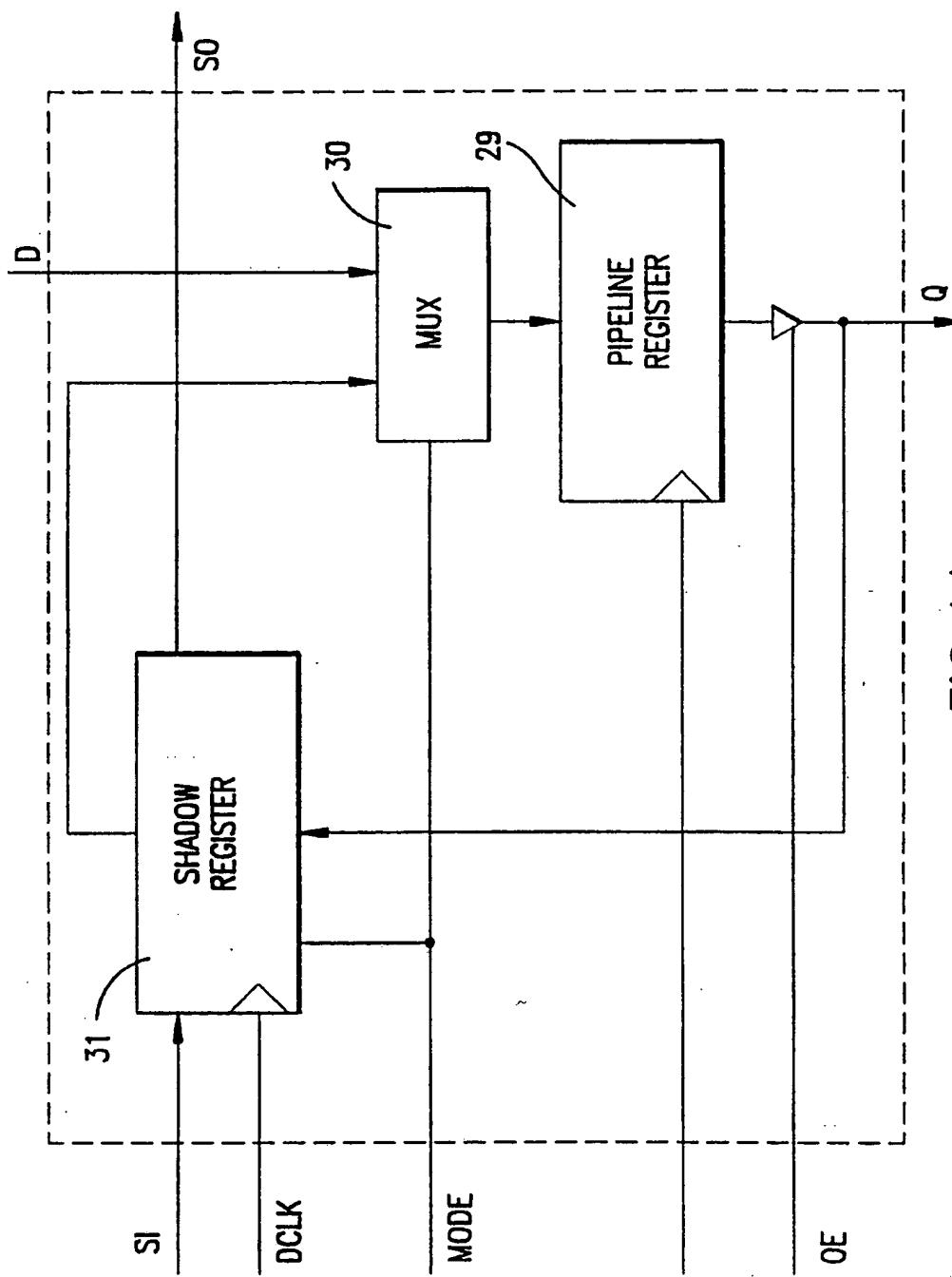


FIG. 11

12/31

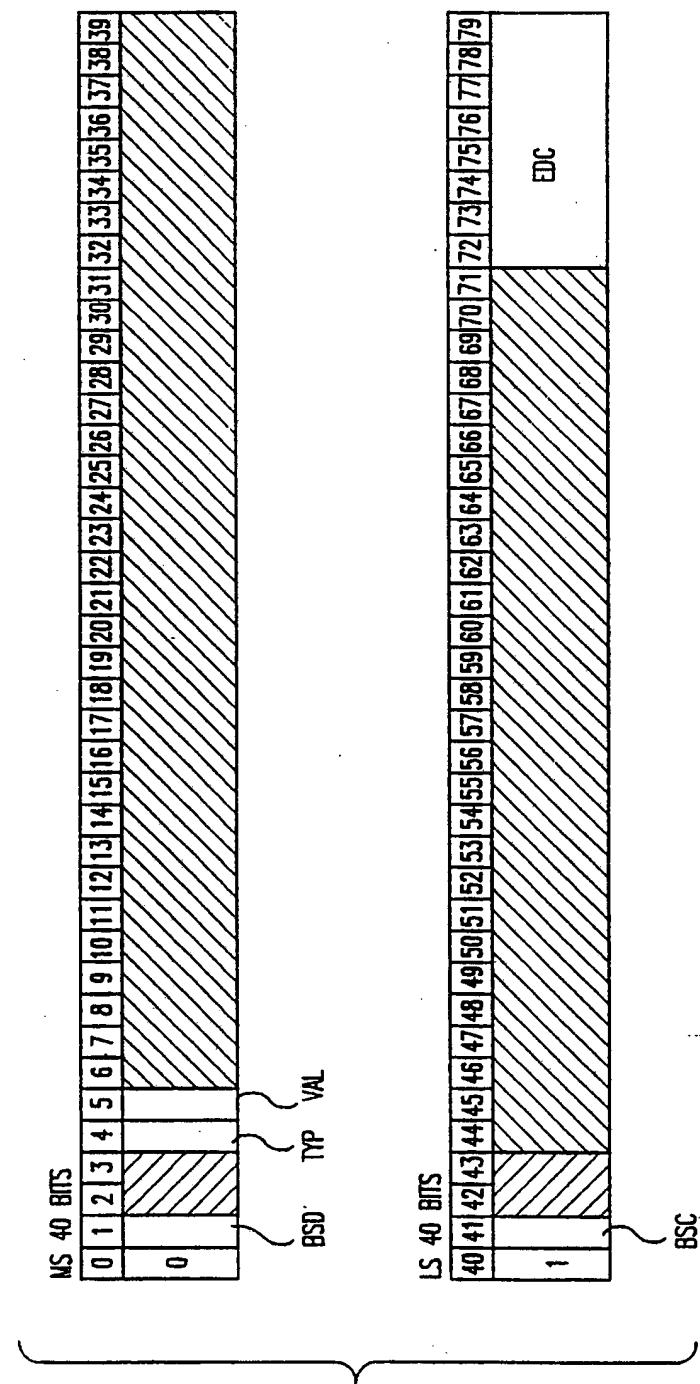


FIG. 12

SUBSTITUTE SHEET

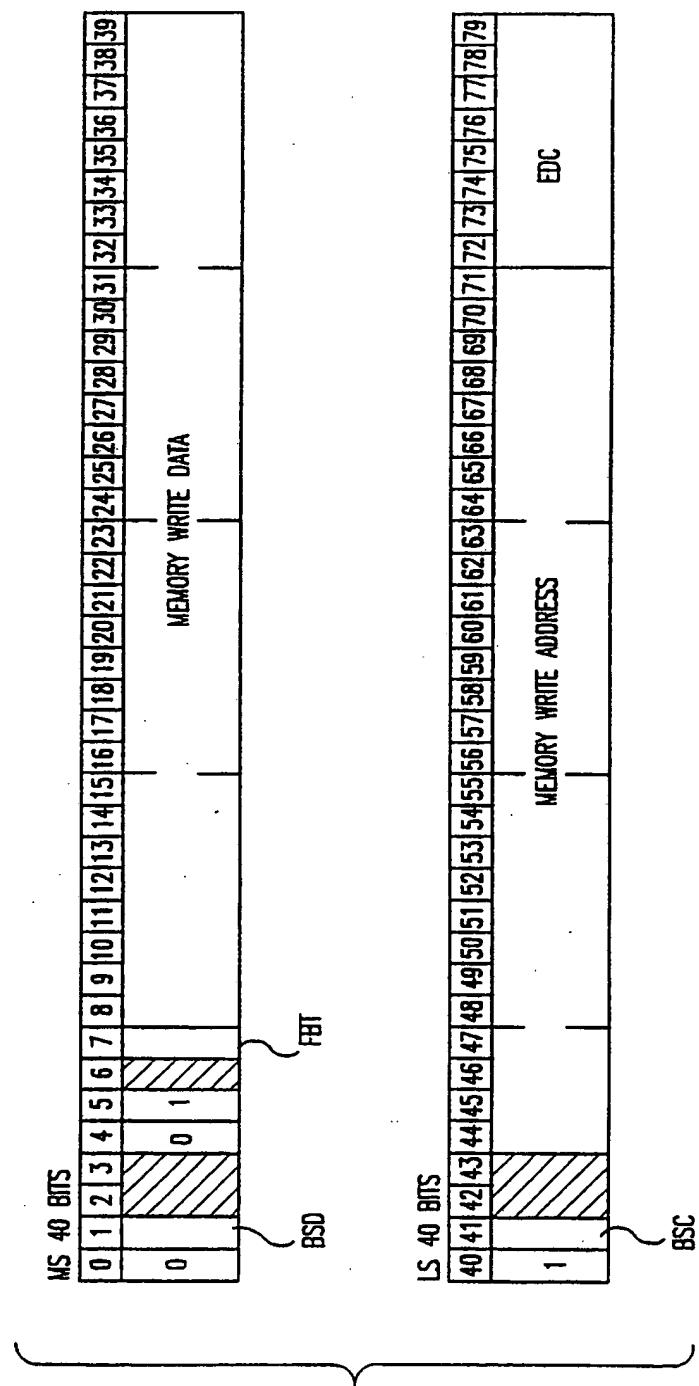


FIG. 13

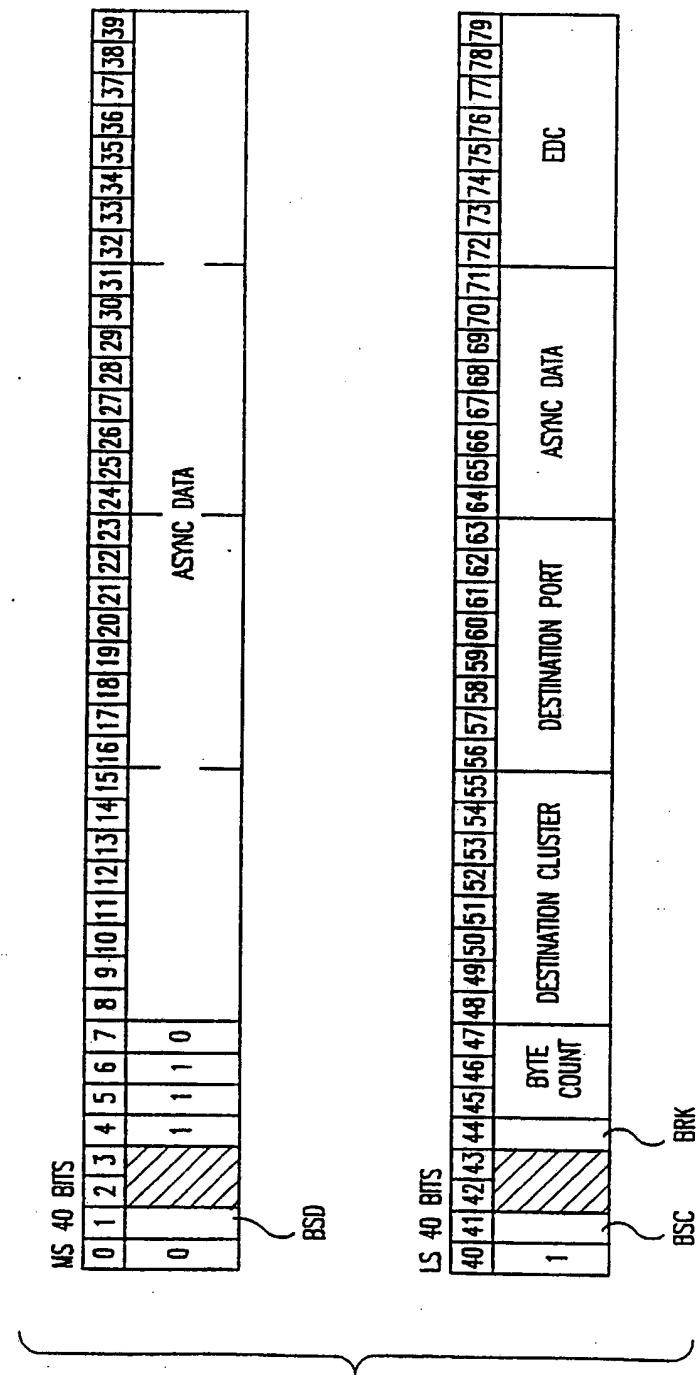


FIG. 14

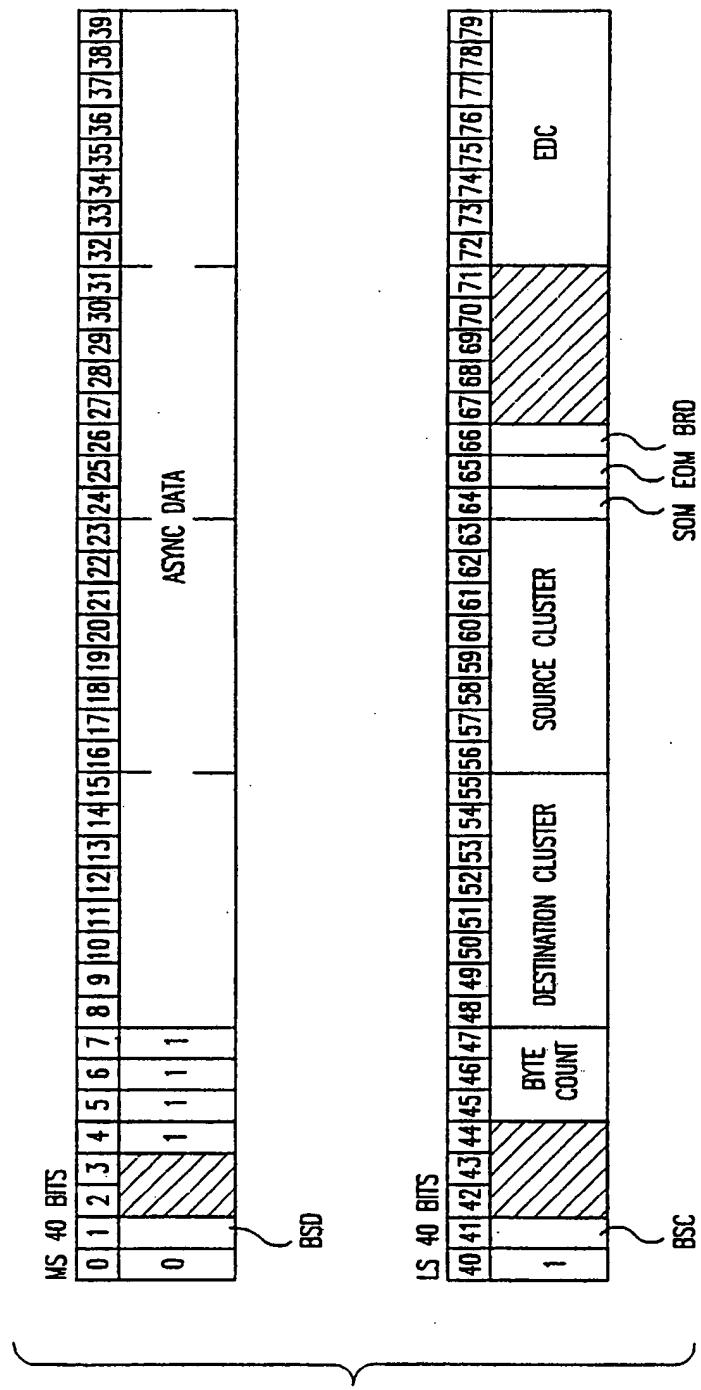


FIG. 15

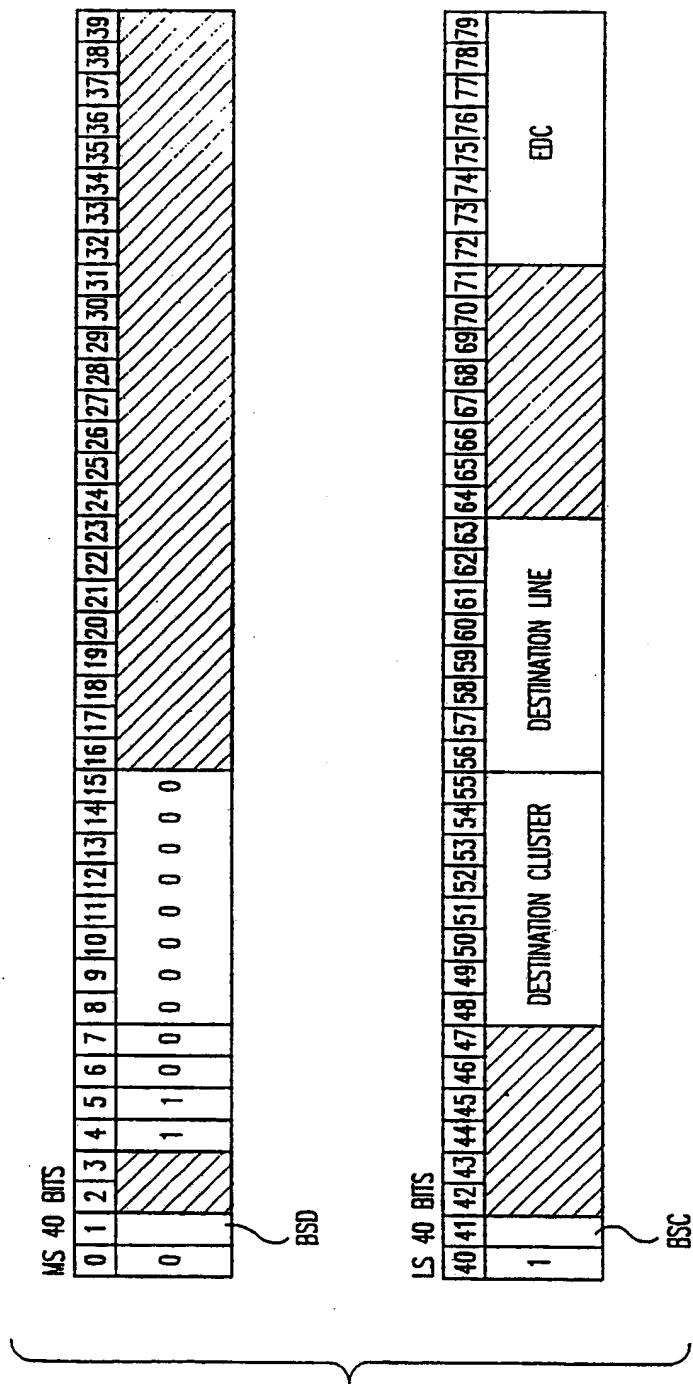


FIG. 16

SUBSTITUTE SHEET

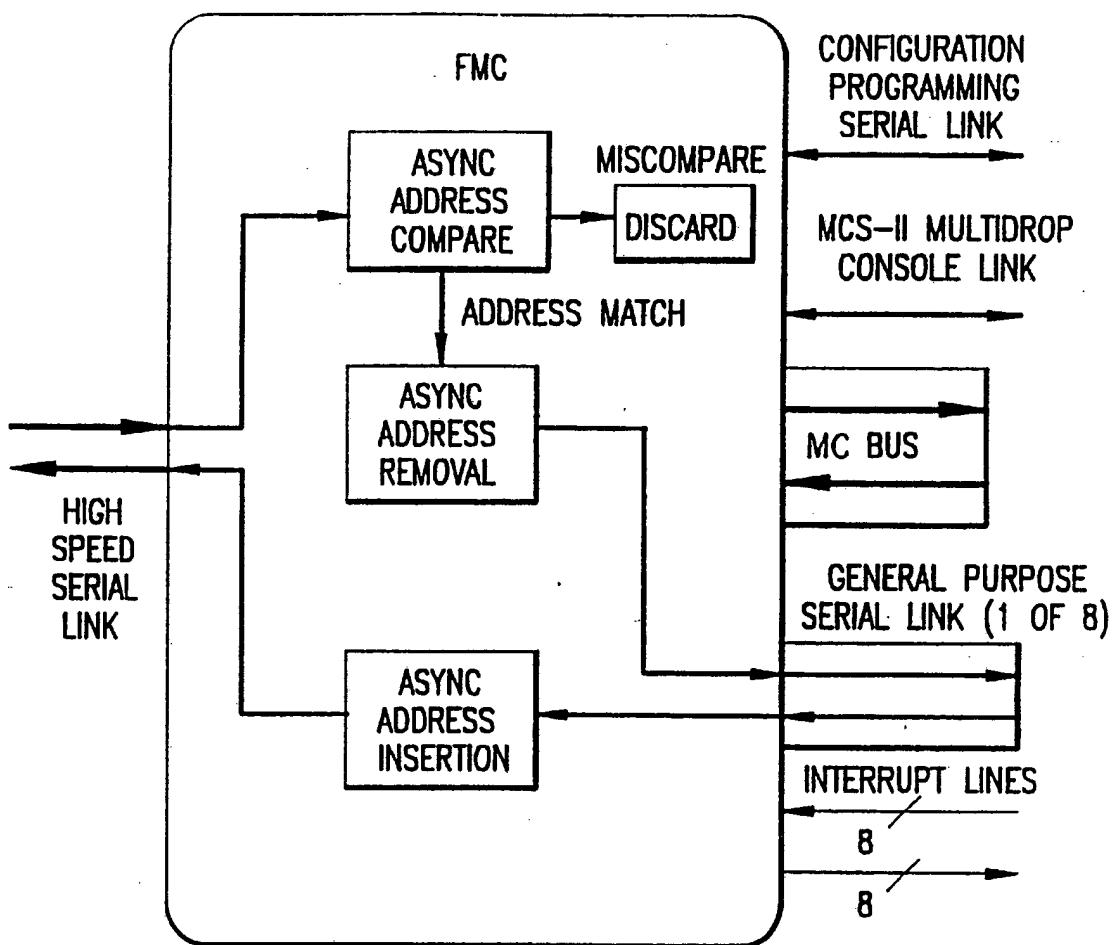
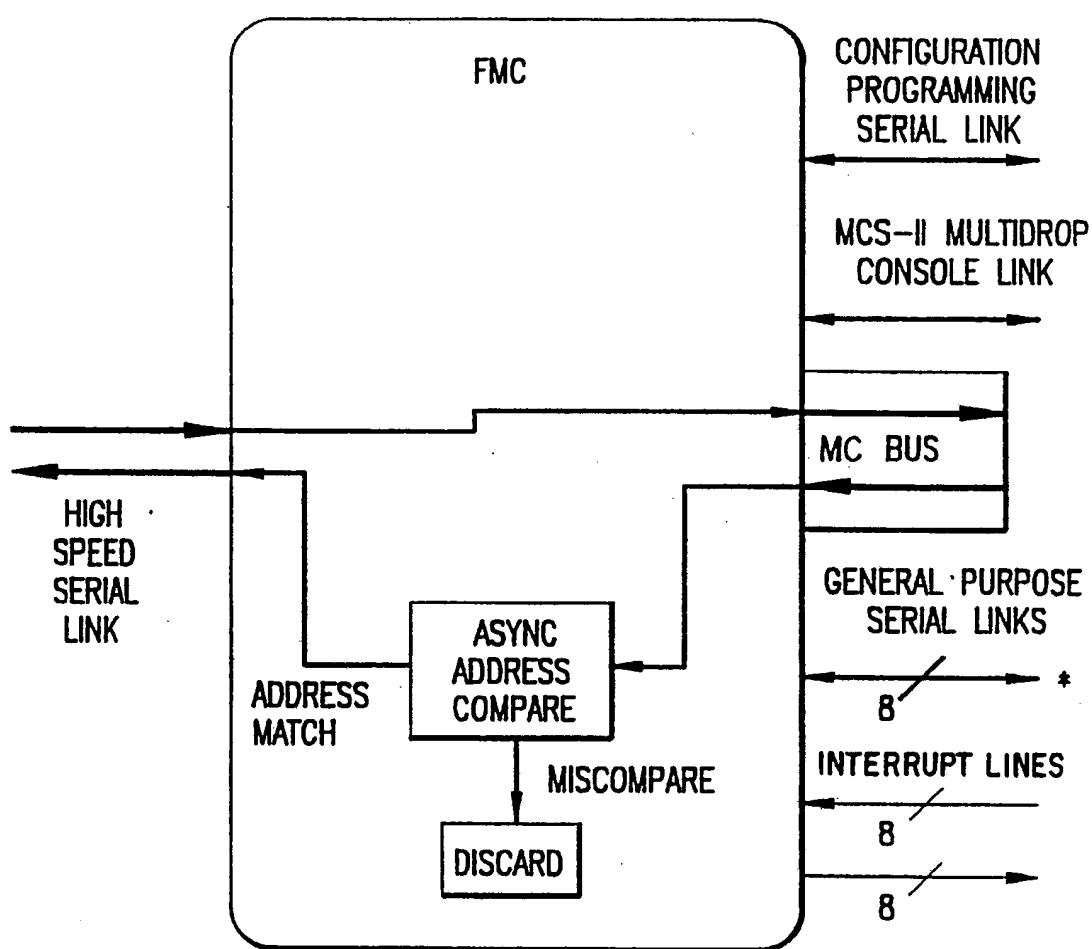


FIG.17



\* NOT CONNECTED

FIG.18

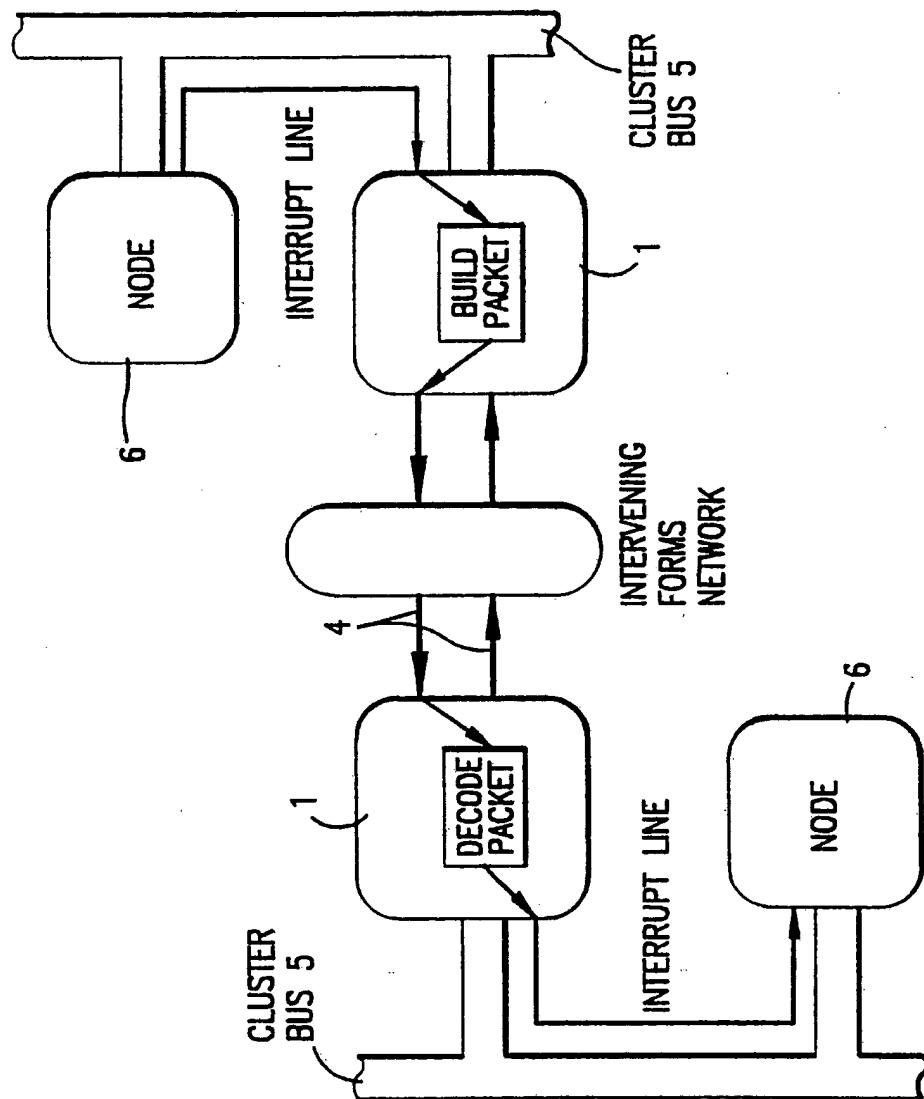


FIG. 19

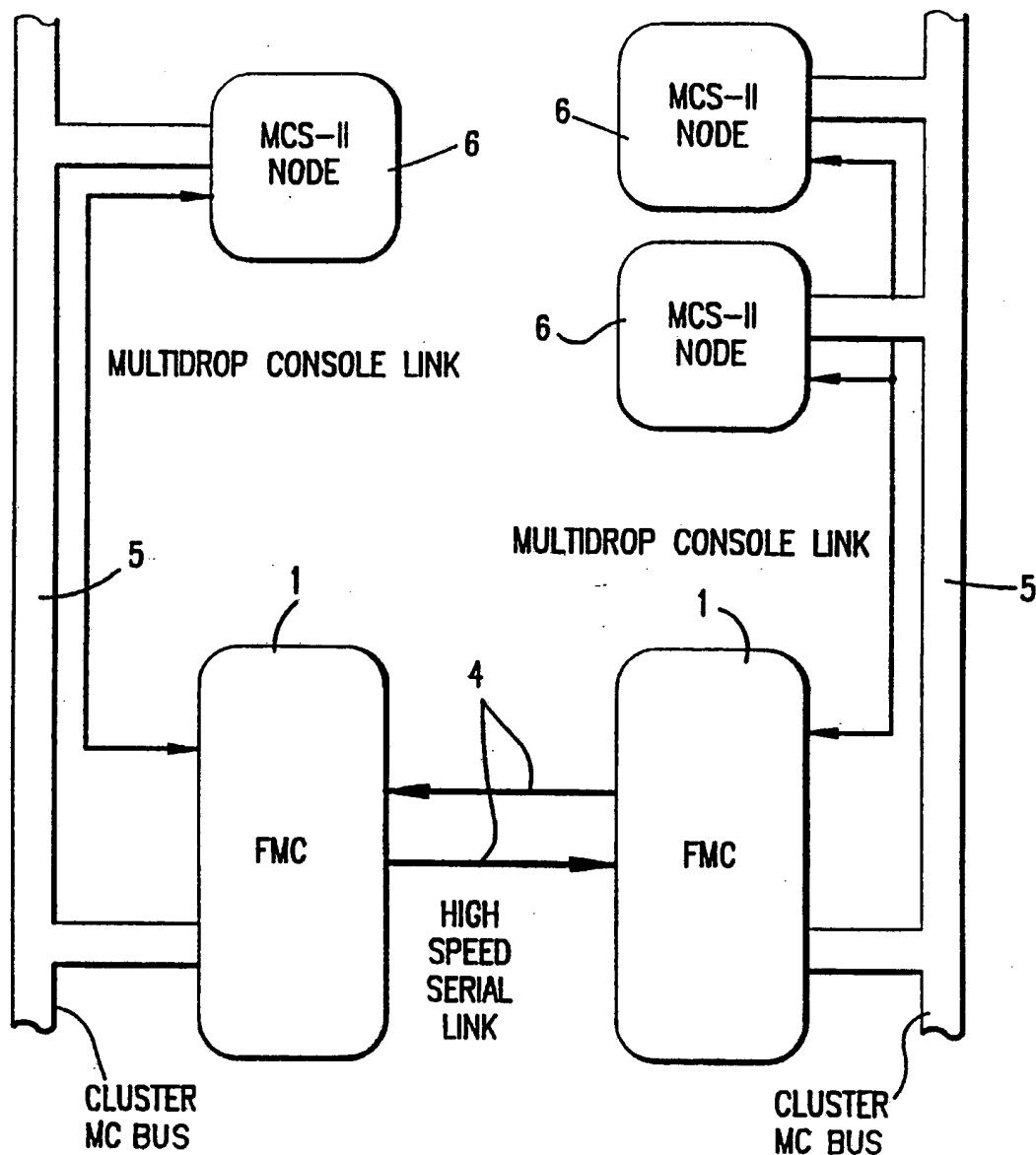


FIG.20

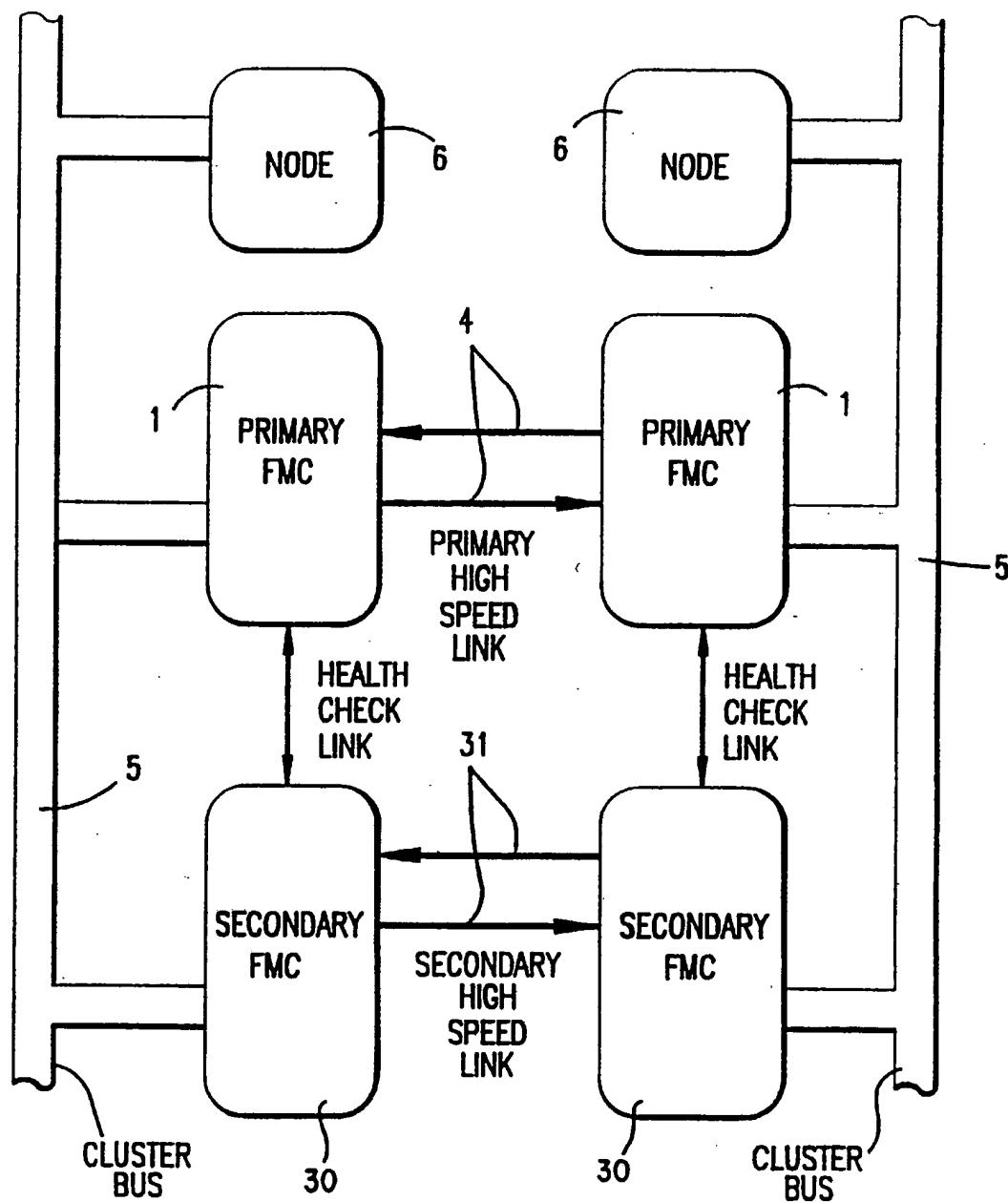


FIG.21

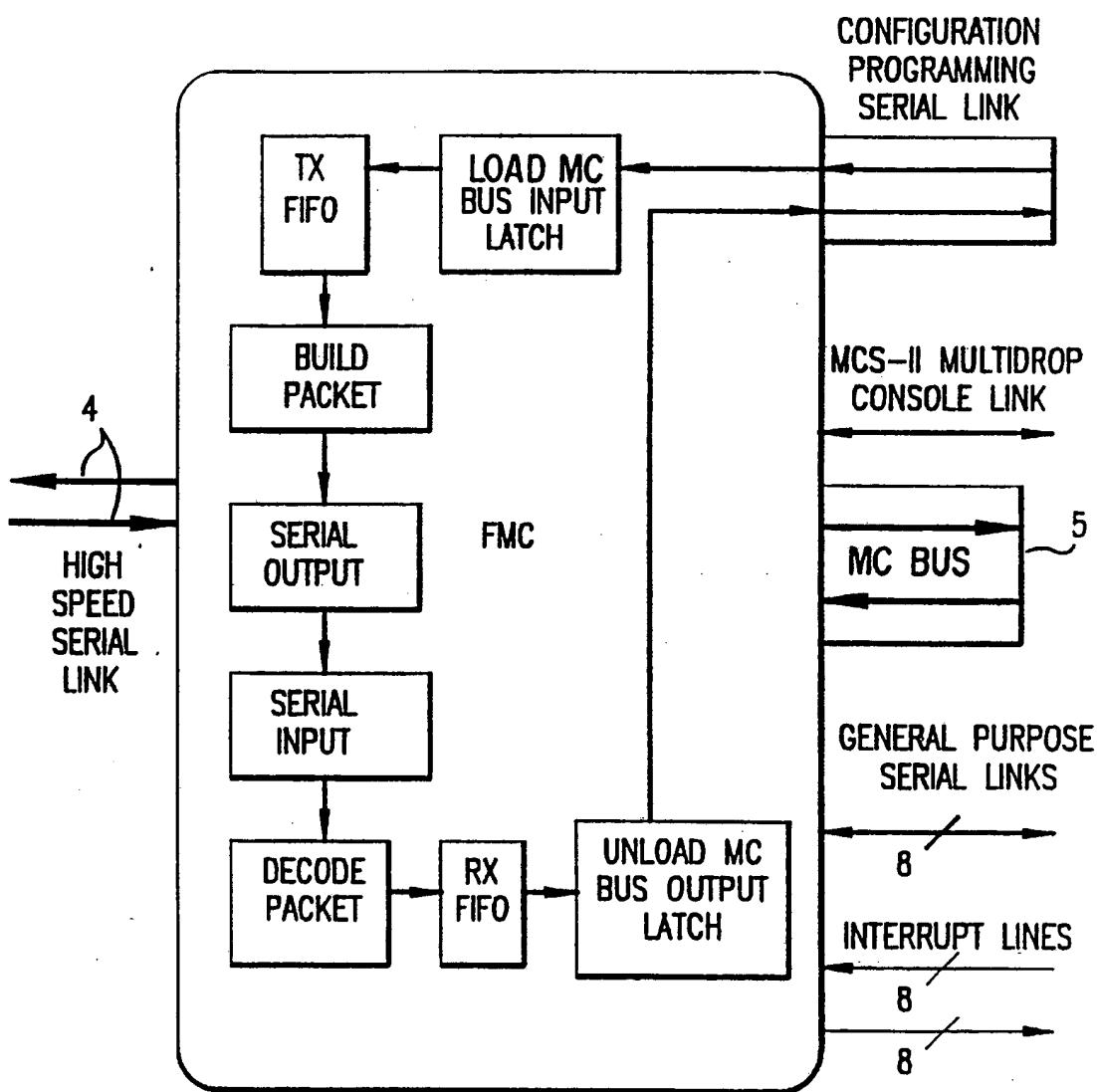


FIG.22

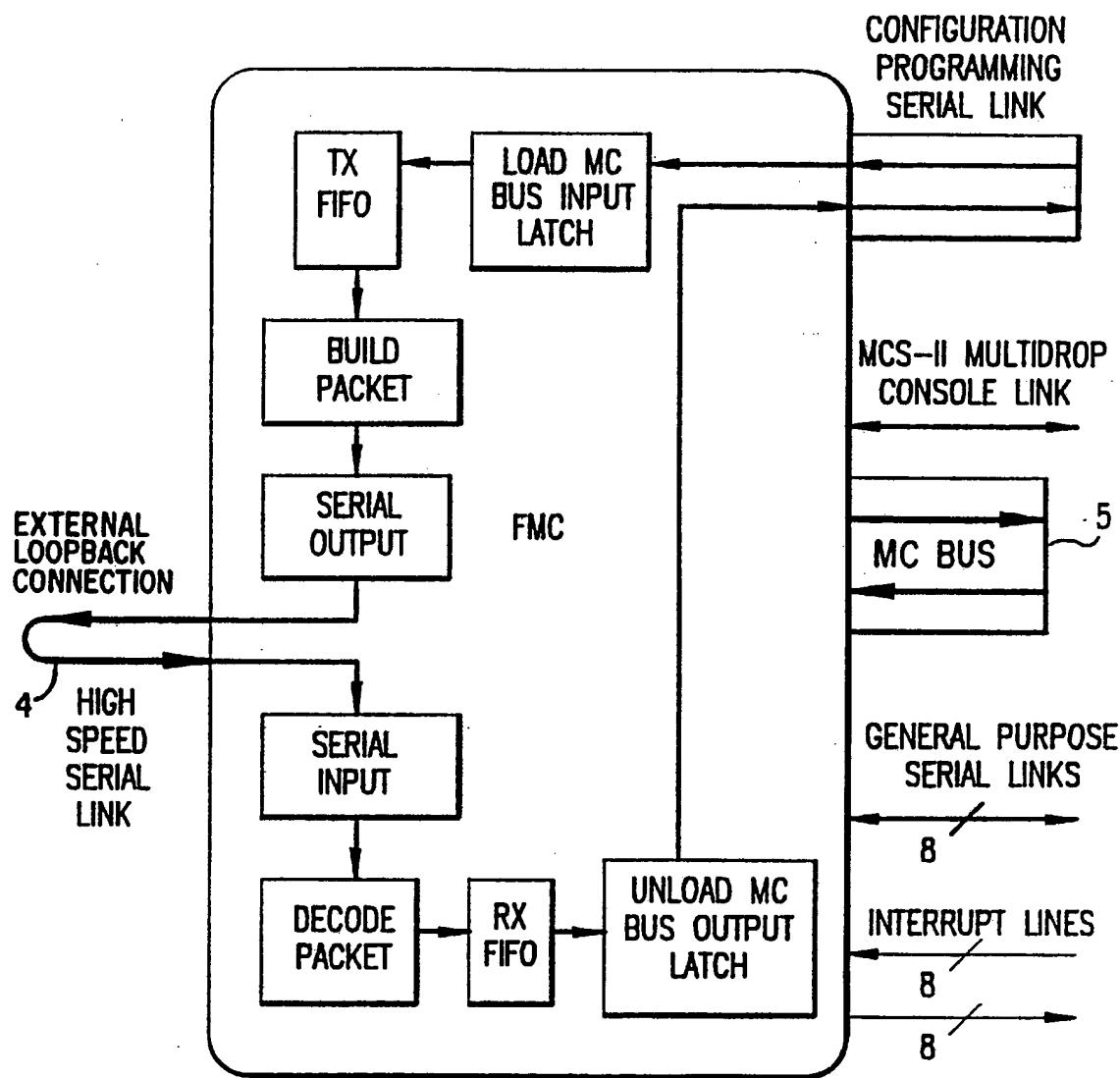


FIG.23

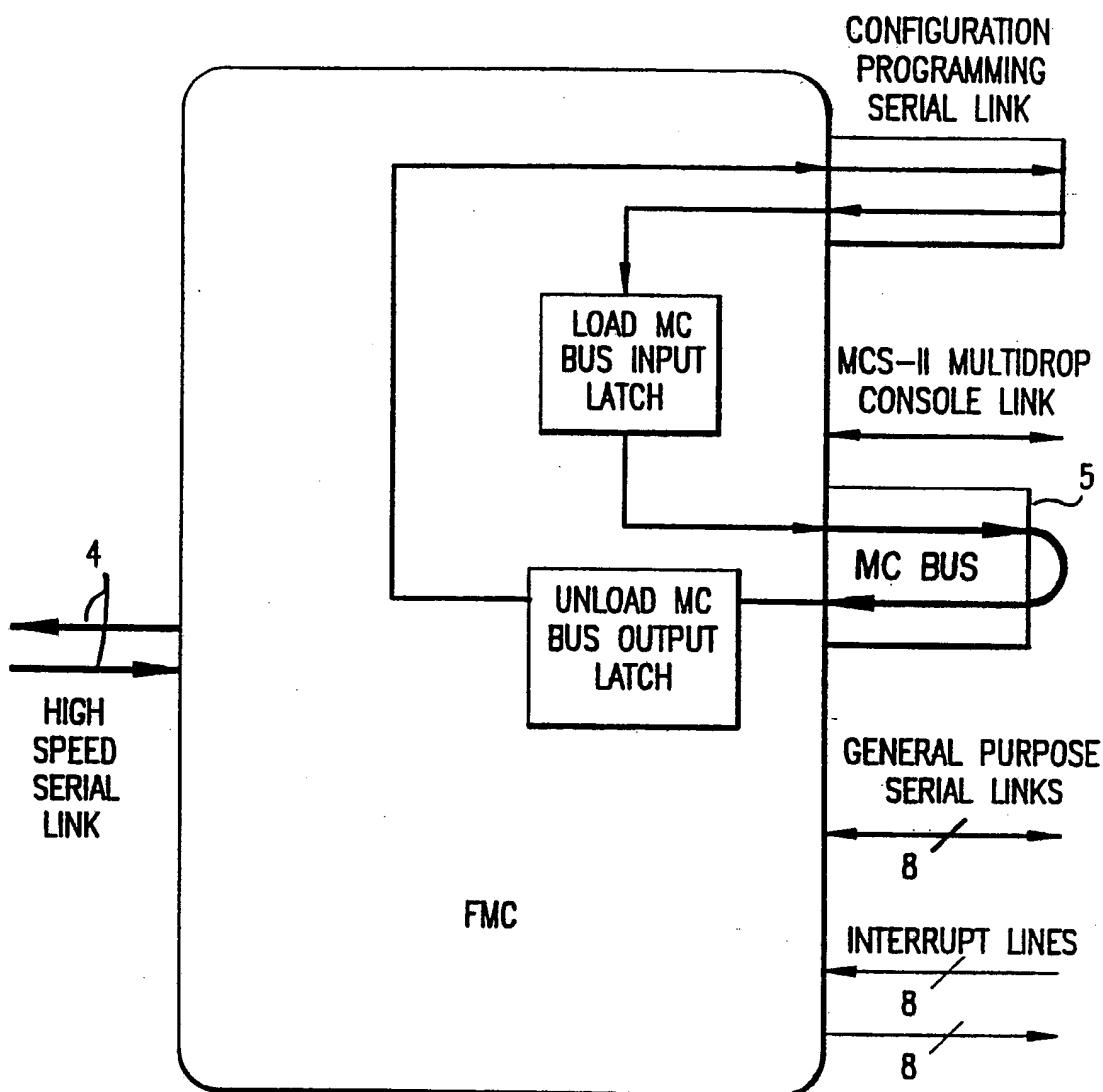


FIG.24

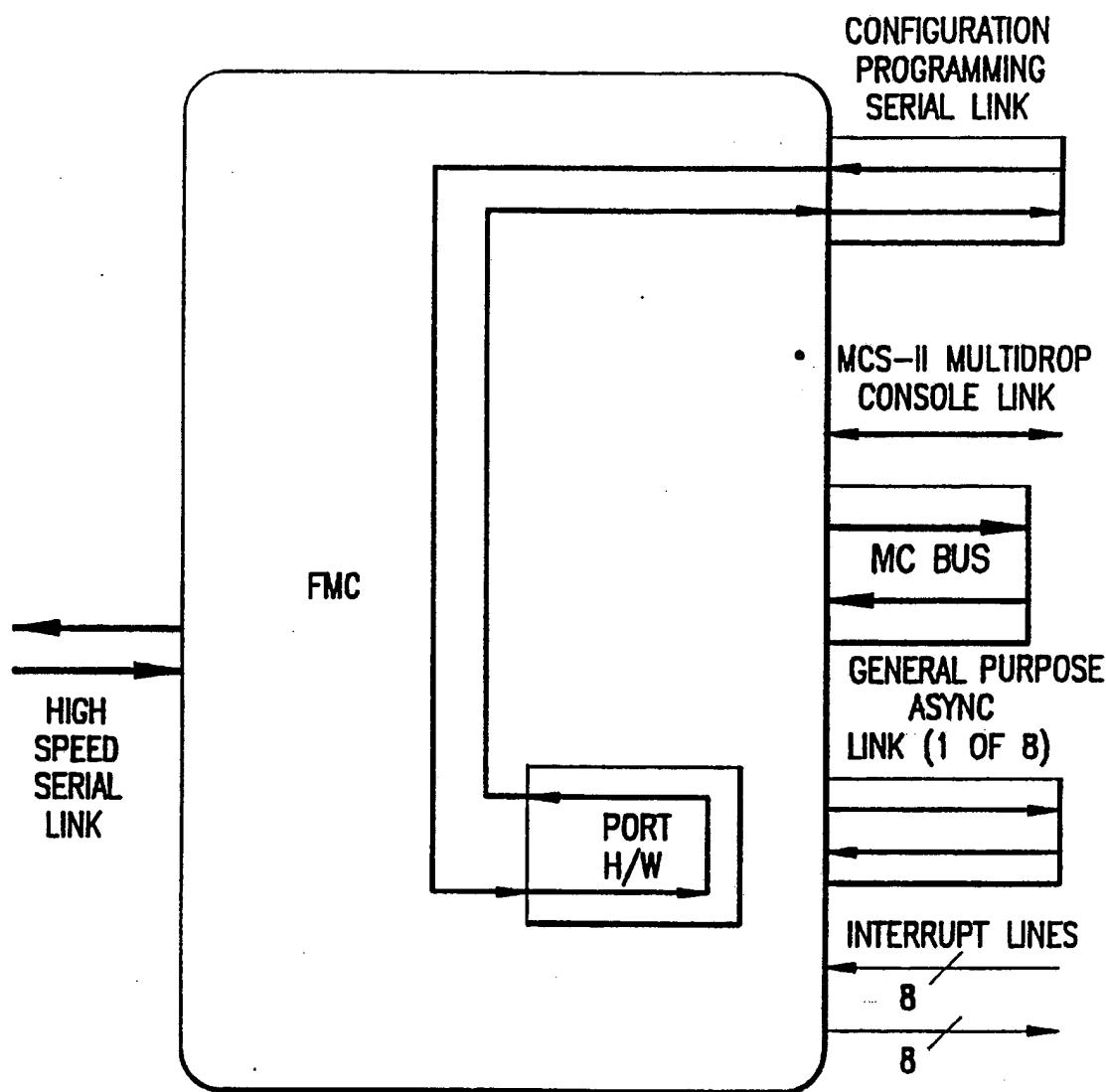


FIG.25a

26 / 31

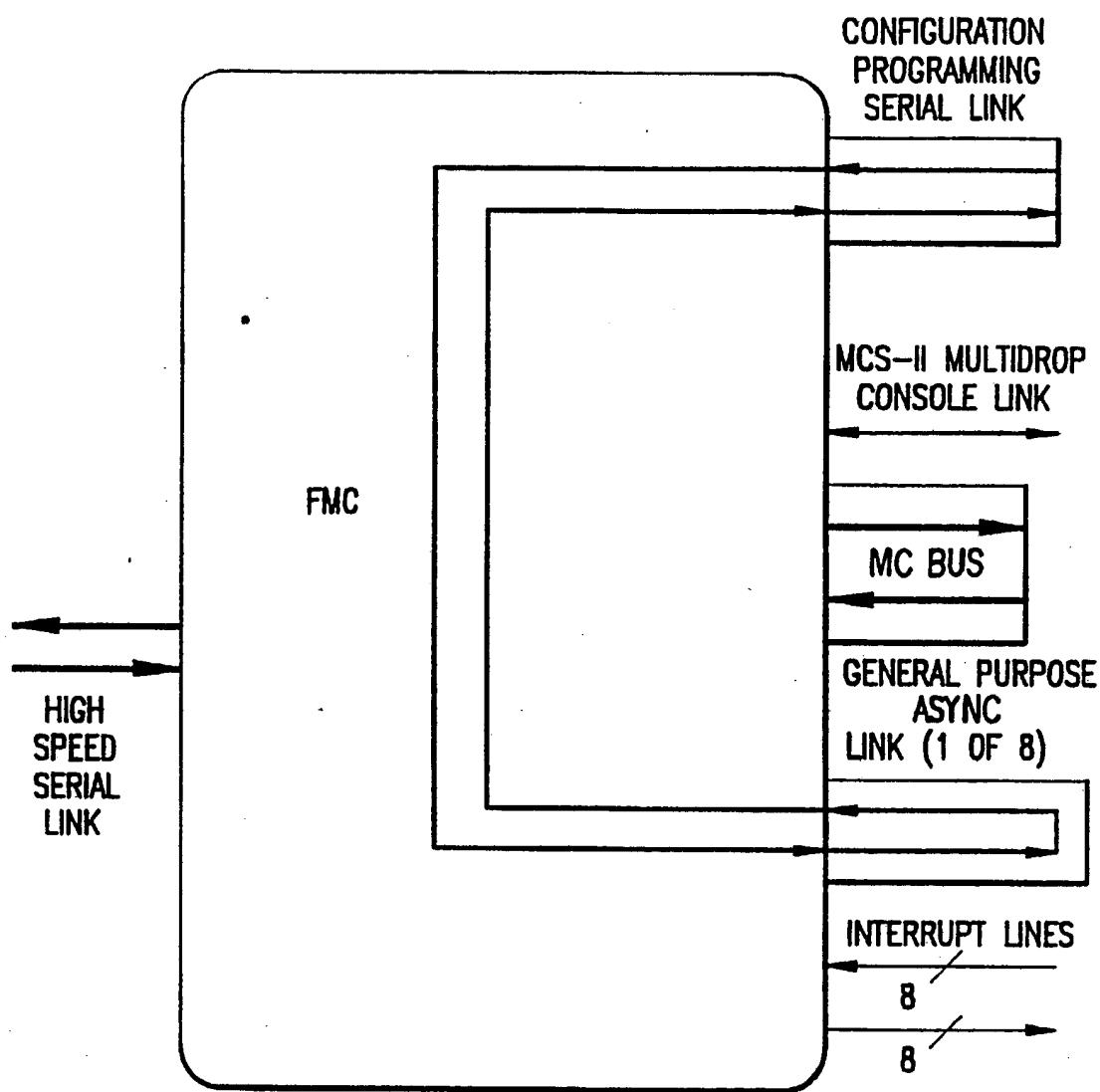


FIG.25b

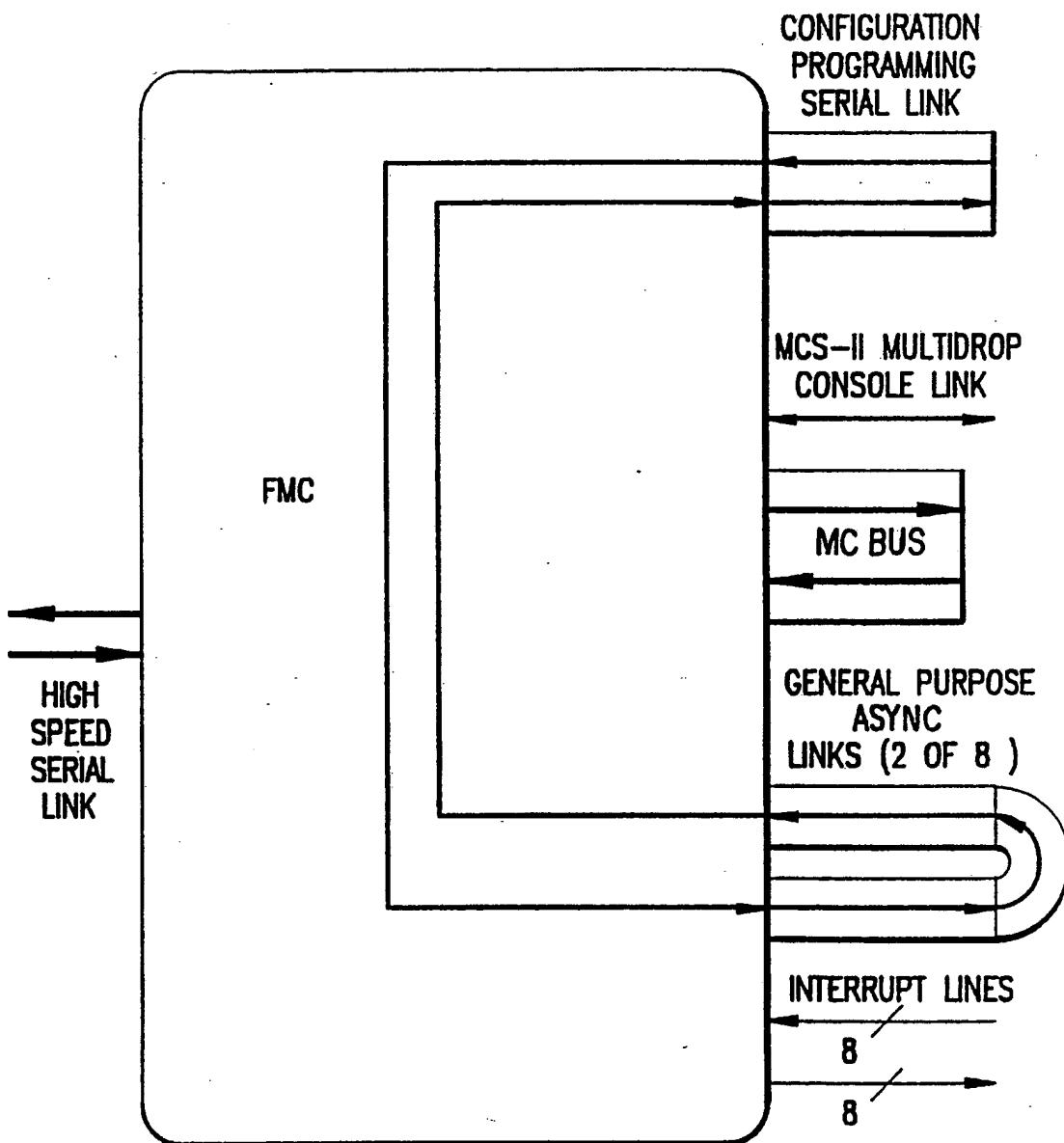


FIG.25c

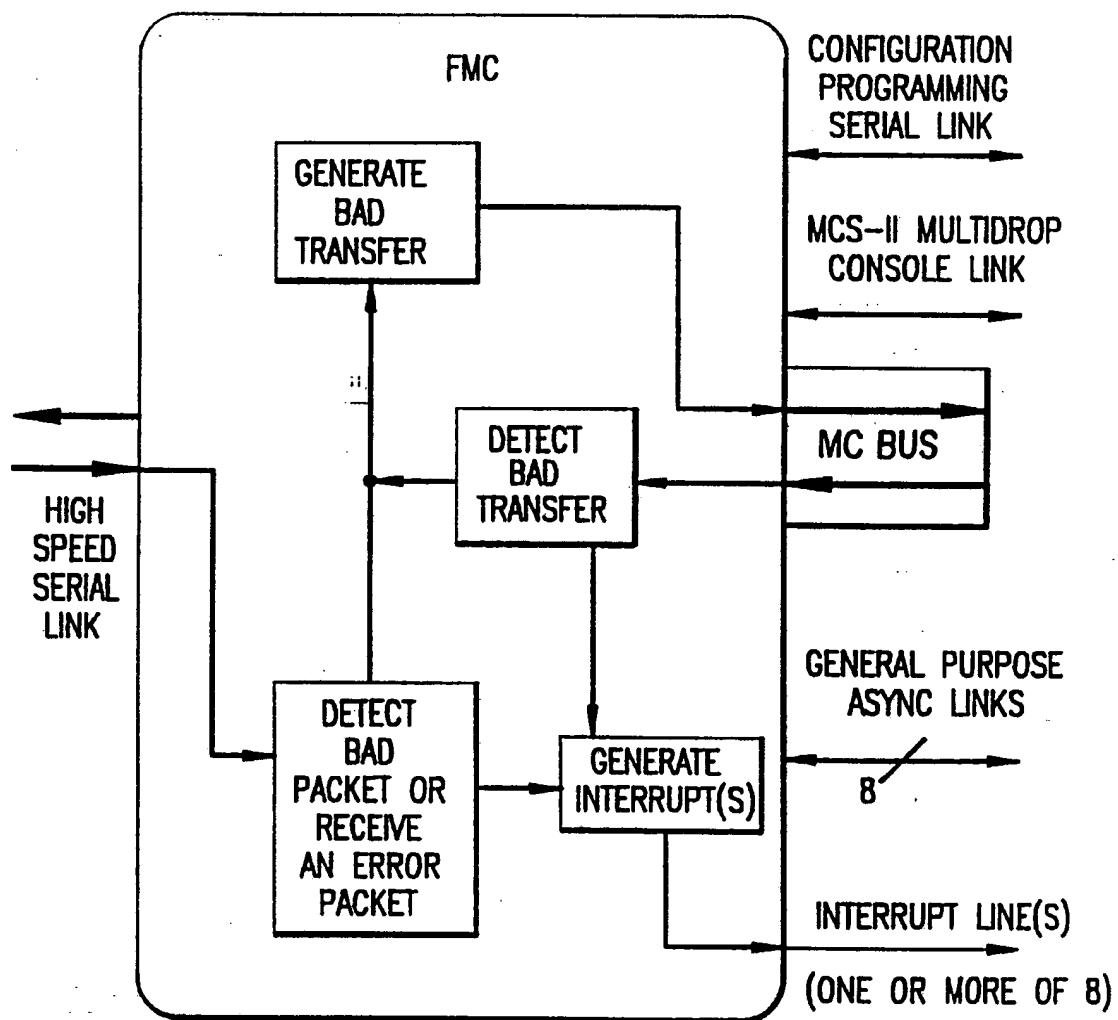


FIG.26

29 / 31

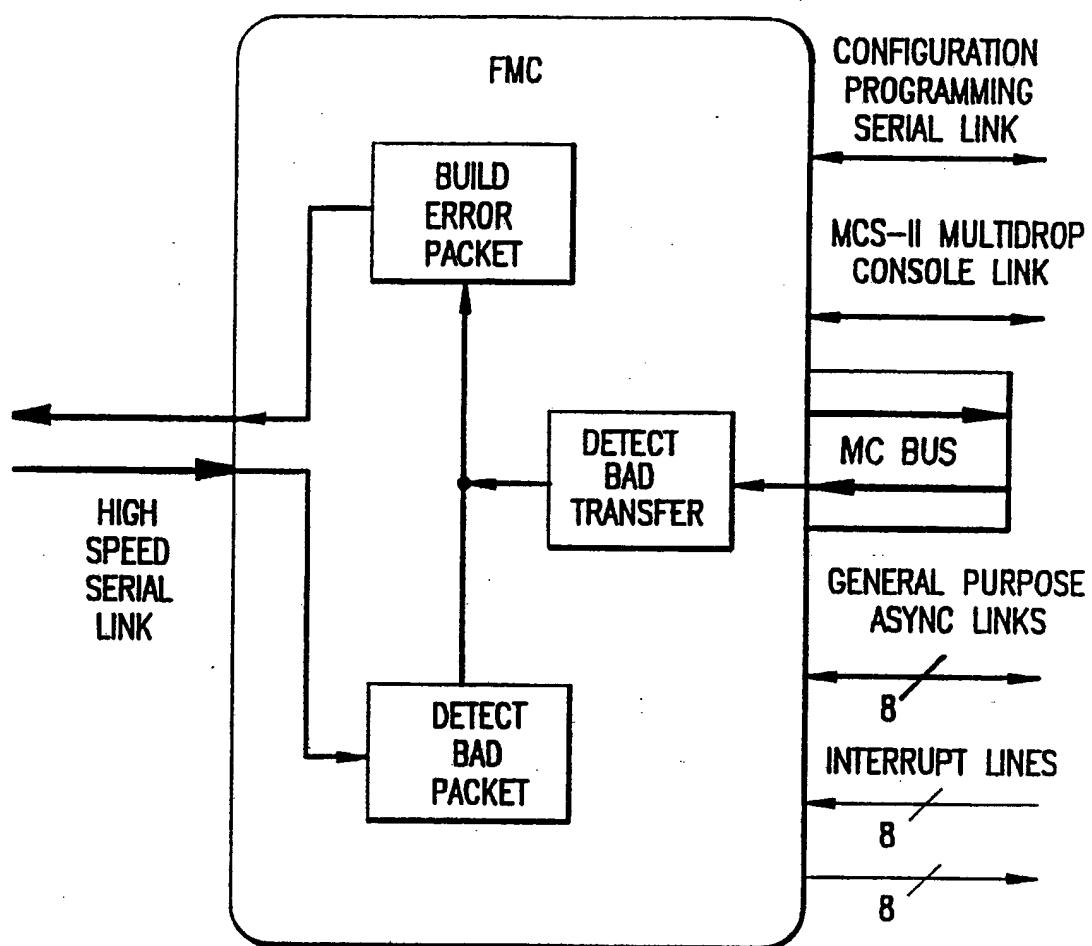


FIG.27

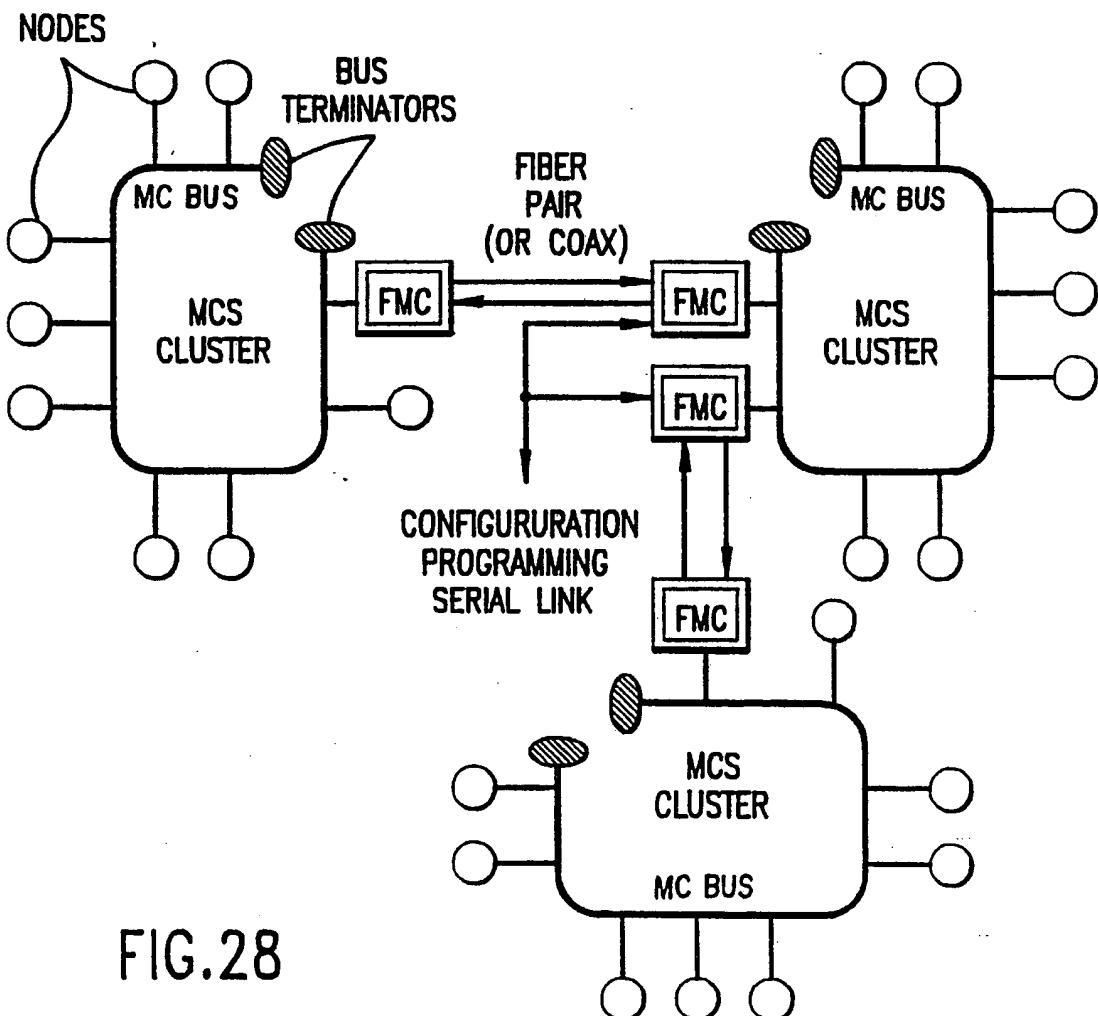
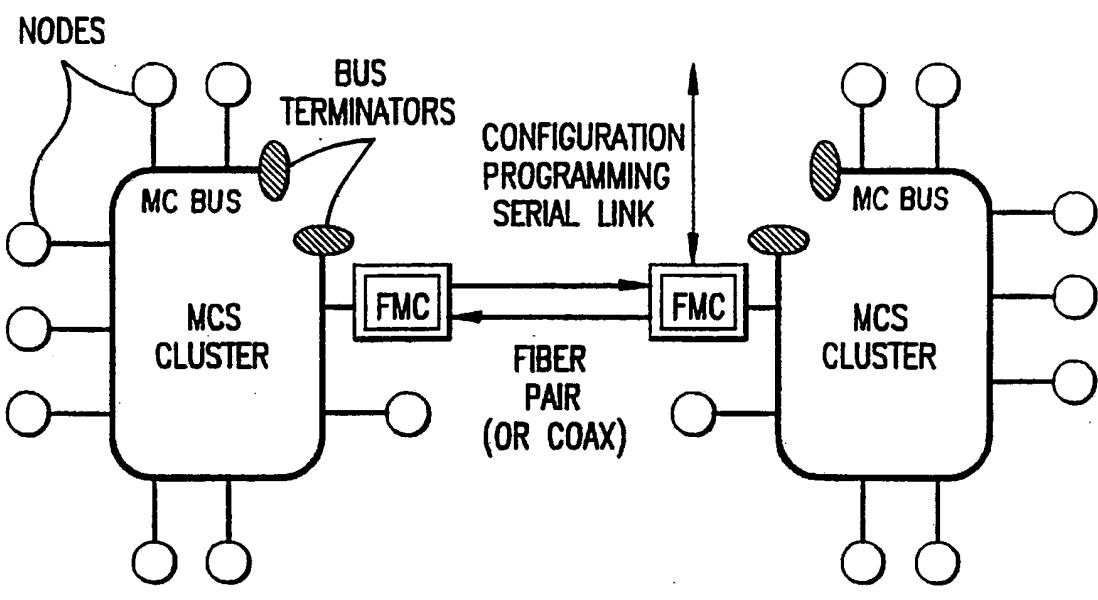


FIG.28

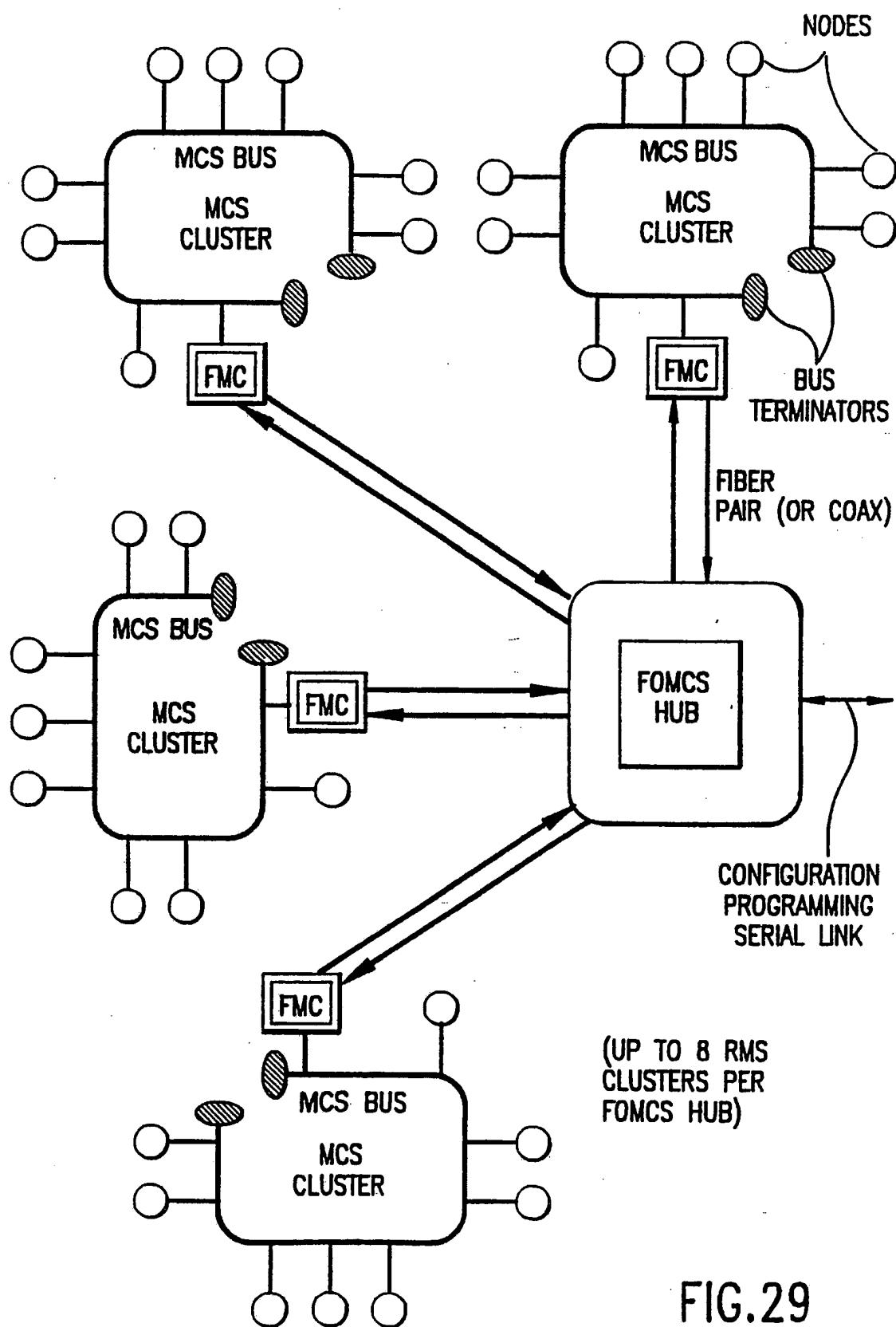


FIG.29

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US93/02839

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :G06F 13/00

US CL :395/200

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 395/325,395/575,395/500

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

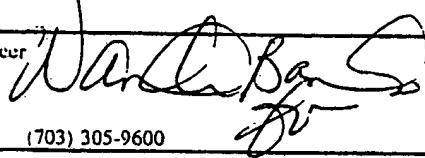
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Please See Extra Sheet.

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y,P	IEEE Network, May 1992, Vetter et al., "Network Supercomputing", p.38-44.	1-4,8,5-7
Y	IEEE, 1992, McFarland et al., "HP's Link Interface Chipset Lu Serial HIPPI", p.229-233	1-4,8,5-7
Y	US,A, 4,466,063 (Segawa et al) 14 August 1984 See the entire document	1-10
Y	US,A, 4,430,699 (Segawa et al) 02 February 1984 See the abstract	1-10

<input checked="" type="checkbox"/>	Further documents are listed in the continuation of Box C.	<input type="checkbox"/>	See patent family annex.
*A*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
*E*	document defining the general state of the art which is not considered to be part of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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*P*	document referring to an oral disclosure; use, exhibition or other means		
	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search	Date of mailing of the international search report
11 MAY 1993	07 JUL 1993
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Authorized officer D. DINH Telephone No. (703) 305-9600
Faxsimile No. NOT APPLICABLE	

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US93/02839

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US,A, 4,269,221 (Lippmann et al) 06 September 1988 See Fig. 1	1-10
A	US,A, 4,935,894 (Ternes et al) 19 June 1990 See the entire document	1-10
A	US,A, 4,342,083 (Freedman et al) 27 July 1982 See the entire doucment	1-10
A	US,A, 4,396,995 (GRAM) 02 AUGUST 1983 See the entire document	1-10

**INTERNATIONAL SEARCH REPORT**

International application No.  
PCT/US93/02839

**B. FIELDS SEARCHED**

Electronic data bases consulted (Name of data base and where practicable terms used):

(FILE 'USPAT' ENTERED AT 11:01)

L1      7 S 4396995/UREF  
L2      510 S 395/200/CCLS  
L3      24433 S MEMORY (P) WRITE#  
L4      175 S L3 AND L2  
L5      192573 S OPTIC?  
L6      25 S L5 AND L4

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